FISCAL YEAR 1984 DEPARTMENT OF ENERGY AUTHORIZATION

(Uranium Enrichment and Electric Energy Systems and Storage Programs)

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
ENERGY RESEARCH AND PRODUCTION

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

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1984 DEPARTMENT OF ENERGY AUTHORIZATION

THURSDAY, MARCH 10, 1983

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research and Production,
Washington, D.C.

The subcommittee met, pursuant to notice, at 2 p.m., in room 2325, Rayburn House Office Building, Hon. Marilyn Lloyd Bouquard (chairman of the subcommittee) presiding.

Present: Representatives Bouquard, Ottinger, Winn, Walker, and Chandler.

Staff present: Louis Ventre, counsel; David Clement, minority counsel; William Harvey, minority energy coordinator.

Mrs. Bouquard. The subcommittee will come to order. Good afternoon, ladies and gentlemen. Without objection our proceedings today may be covered and recorded by the media or other persons during the open session. Hearing no objections, so ordered.

Today we will be receiving testimony on the Department of Energy's fiscal year 1984 budget request for uranium enrichment activities. After receiving unclassified testimony from today's witnesses, we plan to close the hearing to receive classified information on the uranium enrichment program.

The Department of Energy's uranium enrichment activities include management and operation of the Government's three gaseous diffusion plants at Portsmouth, Ohio; Paducah, Ky.; and Oak Ridge, Tenn. The program also includes development of gas centrifuge enrichment technology, construction of the gas centrifuge enrichment plant at Portsmouth, Ohio, and the conduct of research and development activities on the atomic vapor laser isotope separation process. Finally it also includes the uranium resource assessment program.

The committee is extremely concerned about the accelerating decline of the U.S. position in the world uranium enrichment market. Our position in the non-U.S. enrichment market has decreased from 100 percent in 1974 to about 35 percent in 1982, to about 30 percent today. Total value of sales lost to foreign competitors is over $2 billion, with roughly a half billion dollars of this loss occurring during the last year. We are most particularly interested in hearing what the Department is planning to do to reverse this disturbing trend.

The committee has strongly supported the Department of Energy's strategic goal of being reliable suppliers of enrichment services to both domestic and foreign customers. Consequently, we have encouraged research on advanced enrichment technologies which offer significant savings in construction and operating costs. Only by remaining at the forefront of technology can the United States expect to retain its position as the world's largest supplier of enrichment services in the face of the aggressive expansion of foreign enrichment capacity.

While endorsing the Department's goal of being a reliable supplier, the committee is nevertheless becoming increasingly concerned about the tactics being employed to reach this goal. We want to examine the Department's plans to aggressively pursue the development of the advanced gas centrifuge [AGC] and the atomic vapor laser isotope separation [AVLIS] technologies. These are potentially low cost technologies which are our only hope in regaining our stature in the world enrichment marketplace.

We will also be examining the impact which accelerated development of these technologies may have on the pace of the construction of the GCEP.

Our witnesses today are two familiar faces. First, Bill Voigt, Deputy Assistant Secretary for Uranium Enrichment and Assessment, and second Dr. Bob Merriman, director of enrichment and technology, at Union Carbide Corp. Bob is a constituent of mine from Oak Ridge, Tenn., and he will describe the current efforts in the development of both the AGC and AVLIS technologies.

Before we begin to accept testimony from the witnesses, it is my understanding that the ranking Republican member of our subcommittee, the gentleman from Pennsylvania, Mr. Walker, is on the House floor and will join us shortly.

Bill, we look forward to your testimony.

STATEMENT OF WILLIAM R. VOIGT, JR., DEPUTY ASSISTANT SECRETARY FOR URANIUM ENRICHMENT AND ASSESSMENT, DEPARTMENT OF ENERGY, WASHINGTON, D.C.

Mr. Voigt. Thank you, Madam Chairman.

With the Chair's permission I would like to insert my detailed statement for the record and to just summarize the principal highlights of uranium enrichment.

Mrs. Bouquard. You may proceed as you wish. Your full statement will be made a part of the record at this point.

Mr. Voigt. Thank you, Madam Chairman.

The goal of the uranium enrichment program is to meet domestic and foreign utility and U.S. Government requirements for uranium enrichment services in the most economical, reliable, safe, and environmentally acceptable manner possible.

The fiscal year 1984 budget for the uranium enrichment program is $2,240,000,000 for authorization and appropriation offset by $2,240,000,000 in projected revenues.

My office periodically estimates the domestic and non-U.S. nuclear electric generating capacity that will be served by the U.S. uranium enrichment complex. The current forecast is lower than projected in last year's testimony, primarily due to additional delays in and/or cancellations of nuclear power projects.

Delays in nuclear programs, inflationary costs, and an economic slowdown worldwide have all contributed to excess uranium enrichment commitments, large available utility-owned inventories, and associated financial burdens for the nuclear community. This situation, in combination with the pressures of a growing secondary market and aggressive actions by our enrichment competitors, has adversely affected the U.S. share of the enrichment market. In contrast to its previous position of being the sole supplier of enrichment services in 1974, the U.S. share of the non-U.S. market has declined to about 30 percent today. A number of our foreign customers have switched from the United States to Eurodif, Urenco, and the U.S.S.R., and some new business has gone to these suppliers. During 1982, for the first time, a domestic utility terminated its contract with the United States in favor of a foreign supplier. To date, the total value of sales the United States has lost to foreign suppliers is over $2 billion, which the chairman recognized in her opening statement, resulting in a half a billion dollar loss occurring during last year.

Price has become the most important sales consideration to our enrichment customers. The price advantage of $30 to $50 per separative work unit [SWU], that was once enjoyed by the United States, and which existed in 1981, no longer exists. More and more frequently, both the secondary market and our competitors have offered price guarantees at levels below the U.S. price. Their pricing strategy and the fluctuating exchange rates have further aggravated the U.S. sales position. These competitive forces and large secondary market quantities have created market instabilities and significant sales uncertainties for the U.S. enrichment business. The United States is faced with the need to compete in a highly unstable, low price enrichment market while, at the same time, financing the capital investment needed to implement advanced, low cost technologies that are vital if the United States is to maintain a market leadership position in the future.

To meet this challenge, we are taking a number of actions which are designed to enhance the market position of the U.S. uranium enrichment program. Specifically, steps are being taken to minimize the current selling price by reducing costs and optimizing enrichment production activities. A new enrichment contract, the facility requirement contract, is under development to provide needed stability between enrichment commitments and actual requirements by offering greater contract flexibility to our customers. Finally, advanced low cost technologies are being developed and deployed on a schedule designed to meet the most economically attractive enrichment services available to U.S. customers in the post 1990 time period. More specifically, the gas centrifuge enrichment plant [GCEP] is being constructed on schedule and within cost, and the advanced gas centrifuge [AGC] and advanced isotope separation [AIS] technologies are being aggressively pursued. If successful, these steps will maintain and eventually expand the U.S. sales base, thereby enabling significant benefits in terms of domestic employment, balance of payments, and a meaningful contribution to nuclear policies abroad.

That concludes my summary statement, Madam Chairman, and I would be most happy to entertain any questions that the committee may have at this point.

[The prepared statement of Mr. Voigt follows:]

STATEMENT OF WILLIAM R. VOIGT, JR.
DEPUTY ASSISTANT SECRETARY FOR
URANIUM ENRICHMENT AND ASSESSMENT
DEPARTMENT OF ENERGY
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION
U.S. HOUSE OF REPRESENTATIVES

MARCH 10, 1983

Madam Chairman and Members of the Committee, I am pleased to appear before you to discuss the Departments' Uranium Enrichment Program. With your permission, I would like to submit for the record a statement containing a detailed discussion of the enrichment programs. This discussion was also provided to you by Mr. Brewer, Assistant Secretary for Nuclear Energy, who appeared before your Committee on February 22, 1983. I would like to confine my oral comments today to highlights of the enrichment programs.

URANIUM ENRICHMENT

The goal of the Uranium Enrichment Program is to meet domestic and foreign utility and United States Government requirements for uranium enrichment services in the most economical, reliable, safe and environmentally acceptable manner possible.

The FY 1984 budget request for the Uranium Enrichment Program is $2,240,000,000 for authorization and appropriation, offset by $2,240,000,000 in projected revenues.

Projection of Uranium Enrichment Requirements

The Office of Uranium Enrichment and Assessment periodically estimates the domestic and non-U.S. nuclear electric generating capacity that will be served by the United States uranium enrichment complex.

Our mid-range estimate made last summer projected online worldwide nuclear power capacity to be served by United States uranium enrichment capacity to be 135 gigawatts in 1985, 178 gigawatts in 1990 and 204 gigawatts in 1995. Domestic nuclear power capacity included in these totals are 87 gigawatts in 1985, 119 gigawatts in 1990, and 123 gigawatts in 1995. The domestic forecast is based only on reactors currently operating or under construction. Our total forecast estimate is lower than projected in last year's testimony by 2 gigawatts in 1985, 4 gigawatts in 1990 and 22 gigawatts in 1995. The reduced estimate reflects additional delays and/or cancellations of nuclear power projects.

Long-Term Strategy

A long-term production strategy is necessary to permit orderly planning to meet projected uranium enrichment requirements. The strategy is chosen after considering economics, operational risks, and the flexibilities that are available to respond to higher or lower demand levels. In the short term, the strategy calls for lower operating levels of the gaseous diffusion complex and reduced inventories of enriched uranium. Even though the lower operating levels result in the purchase of power below existing contract levels, requiring the Department to pay capacity charges to its power suppliers for power not purchased, it remains the most economical way to operate. Recently completed technical studies indicate that significant risk is incurred from prolonged plant operation below design levels. Accordingly, in FY 1984, the complex will operate at 3,190 megawatts or 530 megawatts above the FY 1983 level.

The strategy also calls for continued design and construction of the Gas Centrifuge Enrichment Plant (GCEP) at Portsmouth, Ohio. The GCEP will initially provide an additional 2.2 million separative work units (SWU) of capacity by 1989 with completion of two process buildings. Completion of the full GCEP (eight process buildings) will be based on either demand for additional capacity or the need to reduce production costs. As less costly gas centrifuge capacity becomes available, the more costly gaseous diffusion plants will be phased out, beginning in the early 1990's. Continued research on advanced gas centrifuge and the atomic vapor laser isotope separation technology provides additional cost reduction opportunities.

United States Competitive Position

At present, the demand for uranium enrichment is relatively static, future sales prospects are limited and uncertain, and many enrichment customers have purchase commitments far in excess of their needs. Some utilities are offering to sell their excess enriched uranium in competition with the primary enrichment suppliers rather than incur substantial inventory costs. This has created a substantial secondary market and corresponding near-term sales perturbations. As a result, a highly competitive situation exists between the primary enrichment suppliers for a fixed market volume. Today, we are facing competitive pressures in the United States and in the international market from several existing suppliers with the following production capacities:

Foreign Enrichment Suppliers and Capacity Levels

Supplier	Capacity (millions of SWU/Year)
Eurodif	10.8 capacity; current production is lower
Urenco	1.0 currently; 2.0 by 1990
USSR	3 currently available for export

In addition to these suppliers, Brazil and South Africa are constructing enrichment plants of modest size, primarily to meet indigenous needs. Japan has announced plans to build a 1 to 2 million SWU plant by 1990 using centrifuge technology in order to realize the announced goal of meeting up to 33 percent of their own enrichment needs. This could limit U.S. sales potential in Japan after 1990. Also, Australia has initiated a feasibility study based on Urenco technology for an enrichment plant which would be available in the mid 1990's. The realization of these enrichment plans will continue to intensify competitive pressures upon the United States.

Delays in nuclear programs, inflationary costs, and an economic slowdown worldwide have all contributed to excess enrichment commitments, large available utility-owned inventories, and associated financial burdens for the nuclear community. This situation, in combination with the pressures of a growing secondary market and aggressive actions by our enrichment competitors, has adversely affected the U.S. share of the enrichment market. In contrast to its previous position of being the sole supplier of enrichment services in 1974, the U.S. share of the non-U.S. market has declined to about 30 percent today. A number of our foreign customers have switched from the U.S. to Eurodif, Urenco and the USSR, and some new business has gone to these suppliers. During 1982, for the first time, a domestic utility terminated its contract with the U.S. in favor of a foreign supplier. To date, the total value of sales the U.S. has lost to foreign suppliers is over $2.0 billion, with about $0.5 billion in lost sales occurring during the last year. In addition to these losses, a great number of direct U.S. sales are being replaced by secondary market transactions. Though sales replacement by excess enrichment commitments originally produced by DOE is understandable, secondary market transactions of non-U.S. enriched material for use as a replacement for U.S. sales is occurring more frequently. Three U.S. utilities and three foreign companies replaced approximately $30 million of potential U.S. sales during 1982 with heavily discounted excess foreign origin enrichment material. All of these sale losses are of great concern to us, and we must reverse this trend.

Price has become the most important sales consideration to enrichment customers. The price advantage of $30 to $50 per SWU enjoyed by the United States in 1981 no longer exists. More and more frequently, both the secondary market and our competitors have offered price guarantees at levels below the U.S. price. Their pricing strategy and the fluctuating exchange rates have further aggravated the U.S. sales position. These competitive forces and large secondary market quantities have created market instabilities and significant sales uncertainties for the U.S. enrichment business. The United States is faced with the need to compete in a highly unstable, low price enrichment market while at the same time financing the capital investments needed to implement advanced, low cost technologies that are vital if the

United States is to maintain a market leadership position in the future.

We are taking a number of actions to enhance the market position of the U.S. uranium enrichment program. We are minimizing the current selling price by reducing costs and optimizing enrichment production activities. We are developing a new enrichment contract, the Facility Requirements (FR) contract, to provide needed stability between enrichment commitments and actual requirements by offering greater contract flexibility to customers. Finally, we are developing advanced, low cost technologies and deploying them on a schedule designed to make the most economically attractive enrichment services available to U.S. customers in the post 1990 time period. If successful, these steps will maintain and eventually expand the U.S. sales base, thereby enabling significant benefits in terms of domestic employment, balance of payments and a meaningful contribution to nuclear policies abroad.

Uranium Enrichment Activities

The budget for Uranium Enrichment Activities as shown in Chart 1 provides funding for three major program activities: (1) Gaseous Diffusion; (2) Gas Centrifuge, and; (3) Advanced Isotope Separation.

CHART I

URANIUM ENRICHMENT PROGRAM

	Budget Authority (Dollars in Thousands)	
	FY 1983	FY 1984
Uranium Enrichment Activities		
Gaseous Diffusion		
Cascade Power	$ 884,000	$ 1,184,000
Other Operations and Support	316,353	297,300
Total Gaseous Diffusion	1,200,353	1,481,300
Gas Centrifuge		
GCEP	588,000	572,000
Other Operations and Support	94,500	109,800
Total Gas Centrifuge	682,500	681,800
Advanced Isotope Separation	50,633	73,000
Program Direction	3,650	3,900
Total Uranium Enrichment Activities	$ 1,937,136	$ 2,240,000
Uranium Resource Assessment	5,000	0
Subtotal	1,942,136	2,240,000
Uranium Enrichment Revenues	-1,968,319	-2,240,000
Total, Uranium Enrichment Program	$ -26,183*	$ 0

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* The net FY 1983 appropriation, after revenues, is $0. The number shown reflects comparability adjustments.

Gaseous Diffusion

The United States presently enriches uranium to the desired U-235 product assay in the gaseous diffusion plants located at Oak Ridge, Tennessee; Portsmouth, Ohio; and Paducah, Kentucky. In these plants, the United States enriches customer-provided natural uranium in the U-235 component for a fee which recovers the cost of providing the services.

In FY 1984, $1,481,300,000 is requested for operation of the gaseous diffusion complex. The three gaseous diffusion plants will operate at a power level of 3,190 megawatts in FY 1984 and produce about 12.1 million SWU. The FY 1984 operating level is consistent with our long-term enrichment strategy and represents an increase of 530 megawatts above the FY 1983 level of 2,660 megawatts. Recent technical studies indicate that prolonged operation below 3,190 megawatts would run a significant risk of extensive equipment failures. This could result in the loss of plant capacity and the release of radioactive material.

The 3,190 megawatt power level is substantially below the 5,781 megawatts we are contractually committed to purchase under existing contracts with the three power suppliers. Consequently, we are contractually required to pay about $243,000,000 in capacity charges in FY 1984 (Tennessee Valley Authority (TVA)--$226,000,000, and Ohio Valley Electric Corporation (OVEC)--$17,000,000) for power under contract that will not be purchased. If the Department purchased power at the contractually committed level of 5,781 megawatts, the FY 1984 power budget would be increased by $680,000,000 from $1,184,000,000 to $1,864,000,000.

We are continuing discussions with the power suppliers in an attempt to reduce the capacity charge payments for power not purchased. As in the past, the success of these negotiations depends on the ability of our power suppliers to transfer contract power not purchased by the Department to other customers. Relief from OVEC for FY 1984 is heavily contingent upon the level of economic activity in the Midwest. Relief from TVA is unlikely at this time because of the surplus generating capacity within TVA's own system, as well as within neighboring systems.

The total FY 1984 cascade power budget, including $226,000,000 in TVA capacity charges, is $1,184,000,000. This is an increase of $300,000,000 over the FY 1983 budget and is due to the purchase of the additional 530 megawatts, increases in the cost of power purchased and increased capacity charges for power not purchased.

Funding requested for diffusion operations, process and long-range technical support, supporting services, capital equipment and construction is $297,300,000. This is a net decrease of about $19,100,000 from the comparable FY 1983 budget. The major decreases are in the requirements for capital equipment and line item construction projects. The only budget increase is in the plant operations account primarily related to existing labor agreements. The requested funds are the minimum amounts needed to operate the plants; to replace equipment that has exceeded its useful life; to properly maintain the plants; and to comply with environmental and safety standards.

New construction projects for the gaseous diffusion program include: storage yards and cylinders for UF_6; general plant projects; utilities upgrading; intermediate gas removal; and power systems protection improvements.

Funding is also requested to continue projects authorized in previous fiscal years.

Gas Centrifuge

The FY 1984 budget request contains $572,000,000 for the construction of GCEP and $109,800,000 for other centrifuge activities.

The GCEP will provide an additional 2.2 million SWU per year of capacity by 1989. This GCEP capacity will be increased to 3.3 million SWU per year through upgrading with advanced gas centrifuge machines now being developed; even further advancement in centrifuge machines now appears achievable.

DOE continues to support the need for GCEP based on the results of the Department's thorough analyses of the alternatives available to the enrichment enterprise. These analyses carefully examine various production scenarios and evaluate the merits of each on the basis of cost, both to the Government and to the customer; impact on U.S. enrichment prices and our competitive position in the international market; energy efficiency; and technical achievability. Construction of GCEP will yield superior benefits both to the Government and its customers in terms of improved economics and production reliability. Even at reduced demand levels, the cost of production from GCEP in current year dollars will be significantly lower than production from the existing electricity intensive gaseous diffusion plants (GDPs). When escalation is factored in, the difference between GCEP and GDPs becomes very large.

The rapid deployment of enrichment technologies capable of reducing U.S. production costs is a necessary and prudent business decision. Our centrifuge technology is the most advanced proven enrichment technology in the world and offers the U.S. the opportunity to halt the erosion in our existing enrichment contract base and to regain its leadership and market share in the international nuclear community. The Advanced Gas Centrifuge and the Atomic Vapor Laser Isotope Separation technologies currently under development by the Department offer the promise of even lower future costs but must reach a more mature stage of development before they can be counted on for production planning.

We have emphasized to all existing and potential customers that appreciable cost reductions are expected in the U.S. enrichment program by virtue of U.S. leadership in and utilization of advanced enrichment technologies. Our customers universally accept the concept that future enrichment prices will be more favorable with the incorporation of the more economical, less energy intensive centrifuge technology being installed in GCEP.

Without GCEP, U.S. enrichment prices will be perceived by our customers as being significantly higher in the future. This fact has been emphasized by our competitors, Eurodif and Urenco. Our competitors stand to gain a considerable market advantage if the potential of GCEP is not realized in the U.S. Though a detailed estimate of potential sales losses is not possible, the continued strength and vitality of a U.S. Government enterprise which produces $2 to $3 billion in annual revenues, of which about one-third represents a positive contribution to the U.S. balance of payments position, is a worthwhile consideration. In this regard, the commitment to building GCEP is a major positive force.

GCEP is making excellent progress and is on schedule with the total estimated cost (adjusted for escalation) constant. Project momentum continues at a high rate as construction progresses. Process Buildings No. 1 and No. 2 are enclosed. In Process Building No. 1, the floor modules for the centrifuge machines and electrical, heating and ventilation systems are installed. Process piping is under contract and installation is proceeding. Site preparation and rough grading for all eight process buildings is complete. The Recycle/Assembly Building is enclosed and a portion of the building has been turned over to the operating contractor. The fire station, central receiving warehouse, mobile equipment garage, the administration building, electrical substations, and several support buildings are finished. Work on the central control room, the Feed and Withdrawal Building and utilities is underway. Through FY 1983, $2,173,520,000 has been authorized and $2,127,845,000 appropriated, with costs of $1,811,493,000 against a total estimated project cost of $7,450,000,000 in FY 1984 dollars. Design of the GCEP Project is over 89 percent complete with seven of the nine major architect engineers having finished their design efforts. Three centrifuge machine manufacturers have constructed and are operating manufacturing facilities in Ohio and Tennessee using corporate funds. All of the centrifuge manufacturers are now fabricating centrifuge machines on production tooling. Centrifuge machines are operating in the Life Test Facility and the Centrifuge Plant Demonstration Facility (CPDF). The CPDF is a full cascade which will be replicated many times in GCEP. Other manufacturing facilities for materials and components for the GCEP project are in place and in production.

In August of 1982, the CPDF became operational with industrially supplied centrifuges. Start-up, operation, and performance of the machines to date have exceeded all expectations in terms of machine reliability and capacity. The balance of plant equipment operation has been equally successful.

The FY 1984 request for other centrifuge operations and support includes funds for startup testing, procedures, and training to support operation of the GCEP. Also included are funds for the Advanced Gas Centrifuge development program, capital equipment and construction. The FY 1984 budget request for these activities is $109,800,000, an increase of $15,300,000 over FY 1983. Costs for GCEP startup activities are increasing by $21,700,000 over FY 1983 and developmental activities are decreasing by $6,400,000. The increase in startup activities reflects the testing of subsystems, preparation of operating and maintenance procedures, and personnel training. These activities are required in order to begin in-plant operational testing in mid-FY 1984, and to assure that Process Building No. 1 becomes partially operational by FY 1985.

The Advanced Gas Centrifuge (AGC) program consists of projects intended to provide production centrifuges with separative capacity substantially greater than the baseline (Set III) centrifuge. The Department is making good progress in demonstrating an advanced centrifuge, designated Set IV, which has separative capacity 1.5 times that of Set III. Efforts, to date, have verified that the speed and improved flow management techniques extrapolated from current technology have the potential of providing the anticipated performance gain. Full-scale centrifuge tests in this program during FY 1983 will establish which design features will optimize overall separative performance and achieve the desire 50 percent improvement.

In early FY 1983, we initiated research and development on a gas centrifuge concept with a potential separative capacity 2 to 3 times greater than the baseline centrifuge. Gas centrifuges developed within this effort are designated as Set V. A key feature of this program is the relatively high payoff it offers for a modest investment. We anticipate that the first phase, which covers two years, will encompass preliminary testing of full-scale machine rotors intended to verify that reliability testing and production design are warranted.

Advanced Isotope Separation

The objective of the Advanced Isotope Separation (AIS) program is to develop and implement a process that has the capability of producing enriched uranium at costs of less than $40 per SWU. In April 1982, the Atomic Vapor Laser Isotope Separation (AVLIS) process was chosen from three competing AIS technologies to proceed to the engineering development phase. The selection of AVLIS resulted from comprehensive technical evaluations of each technology. These evaluations included a risk assessment and an identification of the major technical uncertainties to be resolved prior to the initiation of the detailed design of large scale facilities. For AVLIS technology, the principal uncertainty involved the operability of the uranium collector subsystem. The FY 1983 AVLIS development effort will extensively examine this issue by operating existing testbeds. The goal of this effort is to develop the data base needed to design plant scale testbeds. Efforts will proceed to complete partially constructed testbeds, such as the Materials Handling Development Module (MHDM) which, when operated, will provide a validation of the FY 1983 data base at near plant scale geometries. Experiments will be conducted on enrichment demonstrations using the updated baseline feed and liquid collection of product and tails. Also we intend to complete a new point design using an updated feed concept.

The major AVLIS effort in FY 1984 will be to complete the detailed data package needed to proceed with engineering design and to initiate construction of experimental facilities capable of demonstrating the process at full scale. Technology development funds are also required to provide the information needed to initiate fabrication of the next generation of laser and separator subsystems. In addition, MHDM will become operational at the end of FY 1984. This facility will be used to demonstrate the thermal management of collector subsystems in MHDM. The FY 1984 funding requested for the AVLIS program is required to initiate evaluation of subsystem reliability, lifetime and engineering issues.

Uranium Resource Assessment

Although the data collection portion of the National Uranium Resource Evaluation (NURE) program was terminated in FY 1981, during FY 1982 a tremendous amount of the data were analyzed and made available to the public in reports, maps, and computer tapes. During FY 1983, essentially all of the remaining data gathered through the NURE program will be made available to the public. Thus, the major goals of this program have been achieved.

Department of Energy
Washington, D.C. 20545

BIOGRAPHY
WILLIAM R. VOIGT, JR.

William R. Voigt, Jr., is Deputy Assistant Secretary for Uranium Enrichment and Assessment, Office of Nuclear Energy, Department of Energy (DOE). He has held this post since June 1, 1982. In this position, Mr. Voigt is responsible for the management of a multibillion dollar enterprise related to the production of enriched uranium to fuel the free-world's commercial nuclear powerplants and the use of domestic uranium reserves and resources.

Mr. Voigt has held this position under various titles since the creation of the Energy Research and Development Administration (ERDA), a DOE predecessor agency, from December 1976. In September 1975, he was made Director of ERDA's Nuclear Fuel Assurance Program Office. In the former U.S. Atomic Energy Commission (AEC), he was Deputy Director of the Division of Production and Materials Management. Prior to that, he was Chief, Water Reactors Branch of the Division of Reactor Development from 1961 to September 1966. He had been a reactor engineer in the water reactor program from 1959 to 1961.

He became associated with the AEC program while he was employed by E. I. duPont de Nemours from 1954 to 1956, and from 1956 through 1959 while with the Bettis Atomic Power Laboratory of the Westinghouse Electric Corporation.

Mr. Voigt received a B.S. degree from The Citadel in 1952. He was commissioned and served with the U.S. Army until 1954. He resides in Crownsville, Maryland, with his wife.

Mrs. **Bouquard**. Thank you very much for your excellent testimony.

Looking at the decline in contract sales, what is the real outlook for enrichment revenues in the next 5 to 10 years?

Mr. **Voigt**. Madam Chairman, we expect our revenues to be increasing over the next several years, but against that, of course, are also increasing costs.

I think it is fair to say that the enrichment enterprise, like any other big enterprise, cannot solely use revenues to offset its costs. In other words, major corporations usually borrow money to finance capital expenditures. In the past, the uranium enrichment program has been able to offset its total costs through the revenues received in any one given fiscal year. As to whether or not revenues will be sufficient to offset costs in the future, I think is subject to some question right now primarily due to the uncertainty of the effect of the secondary market on enrichment revenues.

Mrs. **Bouquard**. How vulnerable is our enrichment complex in regards to the secondary market?

Mr. **Voigt**. Right now, it's a very distressed market out there. There are large inventories over and above utilities needs.

Mrs. **Bouquard**. Are the SWU prices on the secondary market comparable to Eurodif or Urenco?

Mr. **Voigt**. It's negotiable on a case-by-case basis. In a distress market condition some utilities are willing to sell at any price to reduce their inventory. They offer enriched uranium at prices less than production costs; not only our costs but Eurodif's costs as well as Urenco's. The secondary market, I think, will not only affect us but will also affect any enrichment supplier.

Mrs. **Bouquard**. At what SWU price could we expect to regain in a significant market share?

Mr. **Voigt**. Again, Madam Chairman, that is subject to some uncertainty. Right now the Eurodif price is somewhere in the range of $120 per SWU.

Mrs. **Bouquard**. This is what I was getting to. It is not a matter of price alone?

Mr. **Voigt**. I am saying that the price has become the single most important element to a foreign utility in deciding with whom they sign a contract.

The devaluation of the French franc and the strengthening of the U.S. dollar has been a factor in Eurodif's capability of selling below our price.

The other factor is, of course, that Eurodif has four dedicated nuclear powerplants. Hence, they are not subject to the same escalation of power costs that we are experiencing with our three diffusion plants. Most of our power is coming from coal-burning plants. Eurodif is paying about 20 mills per kilowatt-hour for power. The average power to our three diffusion plants in fiscal year 1984 is about 45 mills per kilowatt-hour—over a factor of two. As power is about 50 percent of our SWU charge, our competitors have an advantage.

Mrs. **Bouquard**. I noticed on page 5 of your testimony that you stated that last year was the first that a domestic utility terminated its contract with the United States for a foreign supplier. Would you please identify this domestic utility?

Mr. VOIGT. The utility was South Carolina Electric & Gas. It was for 111,000 SWU's amounting to about $16.6 million.

Mrs. BOUQUARD. Did the utility say it saved its ratepayers a substantial amount of money by taking this action?

Mr. VOIGT. I believe that was one of the important considerations that went into their decision.

Mrs. BOUQUARD. Thank you.

We're very happy to have the ranking minority member of the full committee, Congressman Winn, with us.

Mr. WINN. I thank you very much for the kind introduction. I just would like to add that I was not here for your brief testimony. However, I did receive in advance your prepared testimony and had a chance to scan that.

I have two questions that I particularly want to ask. One is about how soon the atomic vapor laser isotope separation process can be ready for commercial production. Do you have any schedules on that.

Mr. VOIGT. Yes, sir. We have recently received a joint proposal from Livermore and Union Carbide which accelerates the program so we can get an answer sooner as to whether that technology will work in a production environment. The proposal would make use of existing facilities so that we can receive an answer in about the 1986-87 timeframe.

Mr. WINN. What's the long-range plan for that? Let's say that it is successful and you get an idea of what you can do with it; has any thought been given to the next steps?

Mr. VOIGT. Congressman Winn, in the event that the AVLIS process is successful technically, and the economics are proven out, then indeed I will be the first to recommend that this technology be put into production.

Mr. WINN. How soon can that be done?

Mr. VOIGT. In the 1986-87 timeframe. If successful, we would displace diffusion plant capacity, which is our most costly production right now, with either the advanced centrifuge or the AVLIS process.

Mr. WINN. As I understand it, there are three companies ready and capable of supplying the Set III centrifuge machine. Is that right?

Mr. VOIGT. That is correct, sir.

Mr. WINN. In the event that the design for the Set V machine were accepted rather than the Set III design which of those Set III manufacturers would be involved in providing the Set V equipment?

Mr. VOIGT. Right now, Congressman Winn, all three.

Mr. WINN. Do they work as a team, as in NASA which has groups which work together?

Mr. VOIGT. Yes, sir, they do work as a team. They share certain information, except that information which they consider to be proprietary within the framework of their commercial interest.

Mr. WINN. For their own vested interest, sure. That is understandable. However, my point is this: If this process were successful in the 1986-87 timeframe that we would have a team, so to speak, on the field working together to proceed probably faster than if each were perhaps going in a different direction.

Mr. **Voigt**. Definitely, we have had a lot of experience in centrifuge. There is a well established team out there, and that is to their advantage.

Mr. **Winn**. Thank you very much.

Thank you, Madam Chairman.

Mr. **Ottinger**. Mr. Walker, do you have questions?

Mr. **Walker**. We are advised that the Set III machine scheduled for installation at the gas centrifuge enrichment plant, has a much lower capability than the Set V centrifuge which is being rapidly developed.

Which portion of the $572 million requested for the program is being used to procure the Set III machine?

Mr. **Voigt**. Within the $572 million, Congressman Walker, there is $146 related to Set III centrifuge machine procurement.

Mr. **Walker**. Is that all the money that is in the budget for the Set III program?

Mr. **Voigt**. No, sir, there are other funds within the budget for the Set III program which is the baseline program of the centrifuge technology.

Mr. **Walker**. I guess my question is: Where else in the budget is there money and how much? Or is that the major portion of the funding?

Mr. **Voigt**. Machine procurement is the major portion of the Set III funding.

Mr. **Walker**. How many Set III machines are being purchased for the total amount that is in the budget?

Mr. **Voigt**. The exact number is classified. We might be able to handle that during the classified section of the hearing, Congressman. I think, on an unclassified basis, I can say that $146 million procures about one-fifth of the machines that would be required for process building No. 1.

Mr. **Walker**. We also understand that basically the Set V machine materials are state of the art and they require no really extensive development. Can you confirm or deny that statement?

Mr. **Voigt**. Did you say Set V?

Mr. **Walker**. Set V.

Mr. **Voigt**. No, sir. Set V centrifuges use a more advanced material than what we are using today. It will require additional development effort as well as reliability testing of the machines themselves, so it is not something we have in hand today.

Mr. **Walker**. In other words, the machine materials are not state of the art?

Mr. **Voigt**. I would like to answer that also in the classified section, if I may.

Mr. **Walker**. Thank you.

Mr. **Ottinger**. Mr. Chandler?

Mr. **Chandler**. I have no questions.

Mr. **Ottinger**. What is the price at which the South Carolina utility is obtaining the SWU's from the French?

Mr. **Voigt**. We do not know the exact price, Mr. Chairman. What South Carolina Gas & Electric bought was not just separative work. They bought an enriched product which is the natural uranium component as well as the separative work component. I have been told that the price of the separative work component was less than what the DOE price is by something on the order of 5 percent.

The uranium price was lower than what they could buy domestically. From that standpoint, then, they got an enriched product for a lesser price.

Mr. OTTINGER. What is the price at which the secondary market is set for SWU's today?

Mr. VOIGT. Right now they are offering SWU's anywhere from $95 to $115 per SWU. This is negotiable on a case-by-case basis because it is what I term a distress market. In effect, they are getting whatever the market will bear.

Mr. OTTINGER. What is the projected price or cost at which SWU's will be produced in the Set III machines?

Mr. VOIGT. On the Set III machines, Mr. Ottinger, if you look at the full eight process buildings, the projection of SWU cost from the GCEP project is about $116 per SWU. That is on a full cost recovery basis.

Mr. OTTINGER. You are contemplating not having that in operation until 1986 or 1987?

Mr. VOIGT. The initial increments will come into operation in September of 1985, the first 1.1 million SWU's in the 1988 timeframe and the first 2.2 million will be in 1989.

Mr. OTTINGER. What concerns me is that it looks unlikely that anything we do with Set III machines will make us competitive with the European market.

Mr. VOIGT. Mr. Chairman, What you have to take into consideration is that the numbers I give you are in current year dollars. If you assume a 9-percent escalation up to the 1996 timeframe, a Set III machine SWU will cost about $174 as compared to a diffusion plant SWU of $284.

Mr. WALKER. That is still the same discount factor which applies to Europe and is unlikely to make us competitive in the world markets.

Mr. VOIGT. If you were to take the three diffusion plants and add a centrifuge to it, in current year dollars our price will be coming down.

Mr. OTTINGER. That is not what I asked. Will they come down far enough so we will be competitive?

Mr. VOIGT. With the deployment of the advanced machine—again, I know you did not ask that——

Mr. OTTINGER. I will get to that next, yes. What I am interested in exploring with you is this: Would it be sensible, and I understand we have a huge amount invested in those first two buildings, and I know you cite figures for a model going full speed ahead with all eight or going with nothing, but I wondered whether some in-between option would not be most advantageous, that is to proceed with the buildings, the two things, and move up to Set IV machines.

Do you have modeling figures on that kind of option? If not, can you get that for us?

Mr. VOIGT. In our yearly assessment of how we should operate this enrichment enterprise, we do take into consideration what the economics are if we proceed with two buildings, the economics of delaying GCEP, and many other options. All of those factors are

Cost Impact of Minimizing Set III Centrifuge Purchases

We have investigated the economic desirability of delaying GCEP construction in order to minimize purchases of Set III machines. For this scenario, we limited the manufacturing rate for Set III machines to only the currently existing machine manufacturing capacity until the Set IV machine is available. This results in purchasing sufficient Set III machines to fill the first process building. Set IV machines are available to fill the second process building. This scenario results in delays in starting up both process buildings. The following table summarizes the cost impact associated with delaying GCEP for the purpose of minimizing Set III machine installations. The data clearly show that this strategy results in higher costs to DOE and its customers primarily because the delay in Process Buildings 1 and 2 production requires DOE to purchase more power at the diffusion plants and also increases GCEP interest costs. The savings associated with having Set IV machines in Process Building 2 are not great enough to overcome these costs.

Cost Increases Associated with Delaying
GCEP to Minimize Set III Machine Purchases

	8 Building GCEP	2 Building GCEP
1984-1993 avg. price ($/SWU)	2.10	0.67
1994-2003 avg. price ($/SWU)	3.49	1.46
Undiscounted TEC* ($ Millions)	1,678	259
Discounted TEC* @ 10% ($ Millions)	526	175
Undiscounted Customer Cost ($ Millions)	1,302	505
Discounted Customer Cost @ 10% ($ Millions) ..	464	170

Assumes FY 1984 dollars, 1%/Yr. power cost escalation in real terms, August 1982 mid demand and 20-campaign period.

* TEC or Total Enterprise Cost is the out-of-pocket cost of producing enriched uranium.

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* TEC or Total Enterprise Cost is the out-of-pocket cost of producing enriched uranium.

Can you give me projected cost figures on AVLIS?

Mr. VOIGT. Our current target, Mr. Chairman, is to achieve separative work equal to or less than $40 per SWU.

Mr. OTTINGER. What about the advanced centrifuge technology?

Mr. VOIGT. The Set V machine, again on full cost recovery basin, may also be in the $40-per-SWU range.

Mr. OTTINGER. Which is nearer to being available?

Mr. VOIGT. I think it is fair to say, Mr. Chairman, that both the Set V and the AVLIS still have to be developed further before you would put them into production. We cannot make that decision today.

As far as Set IV is concerned—and let me give you numbers for that—we are estimating on Set IV full cost, eight process buildings, around $77 per SWU. We are almost there on Set IV. Our goal was to set 50 percent improvement in the Set IV machines over Set III machines. Of the 50 percent improvement we have already achieved 40 percent.

Mr. OTTINGER. If that is so and the Set III machines will not be competitive, and you have excess capacity at the present time, why not go immediately to Set IV and have something which is competitive on the world market instead of going through the expensive process of continuing with Set III?

Mr. VOIGT. The Set IV machine, Mr. Chairman, will not be available for production until the 1989 time frame. We have done some economic assessments as to whether we would delay process building No. 2 to allow this machine to go into it, what the relative economics of that would be.

The economics say no, you do not want to do that, but to continue to procure Set III machines and later retrofit Set IV into those buildings.

Mr. OTTINGER. When you say you have achieved 40 percent of the anticipated savings, that does not mean you have a machine ready to go to achieve those savings?

Mr. VOIGT. I am saying that we have achieved the technology associated with that but it has not been confirmed in our reliability testing program.

Mr. OTTINGER. How much can Set IV be accelerated from that goal?

Mr. VOIGT. I cannot give you an answer now.

Mr. OTTINGER. If it is passed?

Mr. VOIGT. That is under assessment. The latest schedule was, as I mentioned, for 1989 introduction. Whether that can be accelerated, as of right now, I do not have that answer. That is what I am saying.

Mr. OTTINGER. I think that would be very useful to us. We really need knowledge to make decisions.

Can an estimate be made at this juncture?

Mr. VOIGT. All I can say, Mr. Chairman, is that the current schedule gives our estimate as to when we could get the technology to a point where we can say we are satisfied now that this machine can be put into a production facility.

Mr. OTTINGER. Give us what you can ascertain at the present time for the record and how long it would take before you could come up with a firmer estimate on time and cost to accelerate the program.

Mr. VOIGT. I would be glad to.

[The material follows:]

Acceleration of Set IV Program

The Set IV gas centrifuge machines are intended to provide separative capacity 1.5 times that of the GCEP baseline (Set III) machine and to be compatible with the GCEP plant supporting equipment and connections. Set IV hardware and operating conditions are presently being evaluated in a series of individual experiments in full-scale centrifuges. We intend to establish a specific design configuration by the end of 1983. This will incorporate in one gas centrifuge the hardware features and operating conditions we conclude are optimum for Set IV. Progress to date has been excellent. Certain tests have demonstrated that Set IV configurations can reach 90 percent of the total separative capacity desired. The machine integration studies now in progress are expected to validate attainment of the full 50 percent separative capacity improvement by the end of this year.

Our current plan is to initiate long-term reliability testing in mid-FY 1985, with the expectation that Set IV gas centrifuges will be installed in Process Building 3 of GCEP beginning in early 1989. They will also be used as replacements for Set III centrifuges in Process Buildings 1 and 2 as this becomes necessary.

We are evaluating the possibility of accelerating this schedule and results of these analyses are expected in early May. The early indications from these studies would indicate about a 1 year acceleration is not possible unless we are willing to take a significant increase in the risk of machine failure during plant operations.

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Mr. OTTINGER. I understand that the facilities at the Livermore Laboratory which were part of the special isotope separation program [SIS] may be available for use as a demonstration model.

Can you tell me the status of proposals for the use of that facility?

Mr. VOIGT. Yes, sir; we have decided to accept the proposal. In proceeding with the development of the AVLIS process, we will employ the Special Isotope Separation Laboratory [SISL] as a vehicle for getting some of the technology information we need. This is what I mentioned earlier, what I termed the accelerated program where we can get answers out of the AVLIS in the 1986 to 1987 timeframe.

The proposal is looking good to us. We can fund it within the existing 1983-84 budget. However, funds may need to be moved among the operating capital equipment, and construction accounts.

We should be coming forward with a reprograming request to Congress on that in the near future.

Mr. OTTINGER. If that is so, tell me why we should not proceed with the AVLIS demonstration model and make it operational as early as 1986-87 if the SIS facility is used? That is so much advanced.

Why not put our money on that horse and proceed with that as our option which will make us competitive? Why should we do both?

Mr. VOIGT. Mr. Chairman, if I could with full assurance know that the AVLIS process would, indeed, work in the 1986-87 timeframe, I would be the first to recommend we go ahead with that. However, it is like saying you don't want to put anything into production until you see the next increment.

That is also true of the gas centrifuge design. We froze the Set III centrifuge design back in 1977 for the express purpose of getting a machine that was highly reliable and which we could put into production.

We are now proceeding to the phase where the Set IV machine is getting close to that, and then hopefully there will be a Step V machine.

We have over 25 years of experience on the centrifuge. I am saying that the advanced gas centrifuge, the Set V, and the AVLIS are competing with each other as to whether we put one or both of those systems into production.

Mr. OTTINGER. You don't know enough about the AVLIS process to feel comfortable so we can go with that and abandon the centrifuge?

Mr. VOIGT. No, sir. To a degree, Mr. Chairman, when you sign a contract for 10 to 20 years of requirements, you have to be assured you have a process that, indeed, can fulfill that capability.

Mr. OTTINGER. You have that, don't you, with the existing diffusion plants? You just spent $1.5 billion.

Mr. VOIGT. We have that with the existing diffusion plants, but the fact is that if we stay with the existing diffusion plans we have priced ourselves out of the marketplace.

Mr. OTTINGER. If you go through this process, will it not be until well after the 1986-87 timeframe?

Mr. VOIGT. What we are attempting to do, Mr. Chairman, is to compete in the 1990's. Any of the processes we have been talking about this morning apply to that.

Mr. OTTINGER. It looks to me as if you are betting that the AVLIS process will not work. Its economics apparently are projected to be the equivalent of the advanced centrifuge which will be available a good deal earlier. Your insistence upon going with the GCEP looks as if what you are doing is counting on an assumption that the AVLIS with the SIS will not be——

Mr. VOIGT. I am not saying that at all. What I am trying to say is that there is still enough uncertainty in my mind with respect to AVLIS as well as the Set V technology to say, indeed, we cannot count on that for production. To effectively compete in the marketplace, I have to bring on new technology as fast as I can. This is what I am doing through the gas centrifuge enrichment plant.

Mr. OTTINGER. It is a very costly insurance policy you are asking us to underwrite.

Mr. VOIGT. Mr. Chairman, in the event we do not bring on new technology, we will have a very costly loss of a foreign market which is bringing in anywhere up to $1 billion a year of foreign sales into our economy. That has to be weighed as well.

Mr. **Ottinger**. I am not sure I would not like to hear more about the state and anticipated reliability of the AVLIS technology, which has to be assessed before you make that decision.

I think if we are to go with both as an insurance policy, it should be considered we would try to leapfrog to those Set IV machines earlier if that is at all feasible.

Mr. **Voigt**. Again, Mr. Chairman, we have that under assessment. If it can be done, we will surely do it.

Mr. **Ottinger**. I think our good chairlady has returned. I will turn the Chair over to her.

Mrs. **Bouquard**. Thank you, Bill, for your very excellent testimony.

Mr. **Winn**. I have a question, Madam Chairman.

I have just one final question. In conversation with the staff I asked about outside participation. They led me to believe that most participation and cooperation was done in-house. Is that true?

Mr. **Voigt**. Well, there is a lot of work done within house—whereby we have contractors operating Government-owned facilities. However, as you indicated earlier, we are attempting to place much of our program out into the private sector. For example, we are procuring gas centrifuges from private industry.

With respect to the AVLIS process, the program is structured to insure that commercial entities are brought in, for example, for laser procurement. We are attempting to get private industry in put into the program as much as possible.

Mr. **Winn**. Is the administration still interested in the ultimate privatization of the uranium enrichment enterprise?

Mr. **Voigt**. I think it is fair to say, Congressman Winn, that we look at it as a longer-range objective as contrasted to a short-range objective. We have identified that there are a number of developments which have to be made before consideration can be given to bringing the private sector in. Discussions with potential private enrichers have determined that the nuclear community must get back on its feet prior to any private involvement in enrichment.

There are a number of elements within the total nuclear program, that have to be resolved. That is why I say it is a longer-range objective rather than shorter term.

Mr. **Winn**. Maybe I am not making myself clear, but is this not the appropriate time to ask the potential private sector enrichers to conduct detailed studies and recommend business strategies for new technology introduction and marketing? Usually they can be very helpful in marketing.

Mr. **Voigt**. To a degree, we use a marketing organization within my shop. We have utilized the talents of private industry in helping us develop a marketing strategy.

For example, I have discussed the whole marketing program with Du Pont to see whether this would be an approach which Du Pont would use to market a product. The answer was yes. Therefore, within that framework we are bringing private sector expertise into the program.

Mr. **Winn**. Thank you.

Mrs. **Bouquard**. What is the likelihood that revenue problems might necessitate a slowdown of construction of GCEP? How will you deal with this possibility?

Mr. VOIGT. Again, for any one given year you have to balance revenues against total costs. That is a given criterion I use when approaching any given year. I have to look at all the costs within that 1 year, not only for power, but for GCEP as well, when making decisions.

As to whether or not a revenue problem might affect GCEP, I cannot say now. If revenue shortfalls develop, then I would have to look at all elements of enrichment costs, including GCEP.

Mrs. BOUQUARD. You would not expect construction costs to be factored into 1 year in your revenue program, would you?

Mr. VOIGT. That is the way it is approached now.

Say in fiscal year 1984 the totality of our construction projects, including what we are requesting for gas centrifuge enrichment plant is offset by the revenues from silling enrichment services. It is important to note that one of the reasons we have been able to do this over the last 3 to 4 years has been due to the fact that we are able to sell out of our preproduction stockpile. This preproduction stockpile will be depleted in the latter part of the 1985–86 timeframe, except for that needed for our working inventory.

I can then not sell any more from the preproduction stockpile but must meet SWV demand from new production, and my costs go up again. That has to be factored in against the total revenue picture.

Mrs. BOUQUARD. It would be factored in within a timeframe of 2 to 3 years?

Mr. VOIGT. Not from a budget standpoint.

Mrs. BOUQUARD. What is your maximum revenue shortfall which you might anticipate?

Mr. VOIGT. If we were to proceed with the full program as now structured—power, all of gas centrifuge enrichment plant, atomic isotope separation—we could see revenue shortfalls in the hundreds of millions of dollars.

Mrs. BOUQUARD. Thank you very much.

Our next witness will be Dr. Bob Merriman, director of enrichment and technology at Union Carbide Corp.

Bob, you may summarize your statement and proceed as you wish. Your written statement will be made part of the record.

STATEMENT OF DR. J. ROBERT MERRIMAN, DIRECTOR, ENRICHMENT AND TECHNOLOGY, UNION CARBIDE CORP. NUCLEAR DIVISION, OAK RIDGE, TENN.

Dr. MERRIMAN. Thank you.

Since I do have a complete written statement which I have provided, and since much of the information in my statement has been dealt with through Mr. Voigt's excellent statement and the good questions and answers, I would like——

Mrs. BOUQUARD. That is like being the last speaker at a political rally.

Dr. MERRIMAN. That is right. It is a tough act to follow. But, if you have no objection, I would like to take a few minutes and show some Vu-Graphs which summarize my points.

Mrs. BOUQUARD. We would like also to have copies of the Vu-Graph for the record.

Dr. MERRIMAN. Yes.

DWG. NO. K/G-83-770

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INCENTIVE FOR ADVANCED ENRICHMENT TECHNOLOGIES

- CURRENT U.S. SWU PRICES ARE $140–150/SWU
- CURRENT PRODUCTION BASE IS GASEOUS DIFFUSION (GDP)
  - ∿ $100/SWU COST
  - 2350 KW HR/SWU
- COMPETITION AT ∿$100–130/SWU
- GDP + 8-BUILDING GCEP WITH SET III/SET IV MACHINES WILL
  - SIGNIFICANTLY DECREASE ELECTRIC ENERGY REQUIREMENT
  - ALLOW PRICES TO APPROACH $100–125/SWU RANGE IN MID-1990's AND BEYOND (ASSUMING CURRENT PRICING METHODS)
  - STILL LEAVE SUBSTANTIAL PRODUCTION FROM GDPs
- CURRENT SITUATION EMPHASIZES NEED FOR CHEAPER SWUs IN 1990's, NOT NECESSARILY MORE SWUs
- AGC AND AVLIS HAVE THE POTENTIAL TO ACHIEVE PRICES WELL BELOW THOSE OF COMPETITORS

Chart A

UNION CARBIDE

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Dr. **Merriman** [Chart A was shown]. It is a pleasure to talk about my favorite subject, advanced uranium enrichment technologies. Chart A lists the incentive for pursuing enrichment technologies——

Mrs. **Bouquard**. Can you improve the quality of the picture?

Dr. **Merriman**. I will try.

As I said, the incentives for advanced enrichment technologies have been very well outlined already today, namely, that the current prices of SWU's from U.S. enriching plants are $140 to $150 depending upon the contract. Our current production capacity is gaseous diffusion which costs us about $100 a SWU to operate, but which represents a large commitment to use high-cost electric energy.

Mr. Voigt cited some numbers for secondary market and Eurodif competition. The committee pointed out the incentives for getting competitive as quickly as possible.

We think a diffusion plant plus an eight-building centrifuge plant with Set III and IV machines as presently scheduled will, of course, significantly reduce our dependence upon electric energy. It will allow prices, using the current method DOE uses to project prices, to approach the $100 to $125 per SWU range in the mid-1990's and beyond. However, it will not provide the large margin of distance between us and our competition we would like to have in order to be more aggressive in the marketplace.

The way the situation looks to a technologist is that what we need in the 1990's is not more SWU's but cheaper SWU's. The advanced gas centrifuge program and atomic vapor laser isotope separation program have potential to achieve prices well below those of our competitors.

I would like to summarize those two programs very briefly at this time. [Chart B was shown.]

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AGC PROGRAM SUMMARY

- SET IV
  - CURRENT MATERIAL
  - HIGHER SPEED
  - DEMONSTRATE 1.5X SET III CAPACITY IN 1984 (CONSISTENT WITH DEPLOYMENT IN LATE 1980's)
- SET V
  - ADVANCED MATERIAL
  - HIGHER SPEED
  - DEMONSTRATE 2X–3X SET III CAPACITY IN 1986/1987 (CONSISTENT WITH DEPLOYMENT IN EARLY 1990's)
- JOINT EFFORT
  - UCC–ND
  - U Va
  - BOEING
  - AiRESEARCH MFG. CO.
  - GOODYEAR
  - ELECTRO–NUCLEONICS

Chart B

UNION CARBIDE

UNCLASSIFIED

Looking first at the advanced gas centrifuge program, there are two primary elements, the Set IV and V programs.

The Set IV effort utilizes the current material which has been used in making centrifuge rotors for several years. It achieves improvements in performance primarily by operating at higher speeds.

The objective of the Set IV portion of the program is to demonstrate a machine having a capacity of 1.5 times the capacity of the Set III machine in 1984.

This would be consistent with deployment of these machines in space in the late 1980's.

In the Set V program we utilize an advanced material. It achieves further gains through further increases in speeds. The goal of that portion of the program is to demonstrate a machine having a capacity of two to three times that of the Set III machine in the 1986–87 time-frame, consistent with deployment in the early 1990's.

Mrs. **Bouquard**. That is a pretty broad spread. Would you bring it down closer than that? Are we talking 2 years, 4 years?

Dr. **Merriman**. In the case of the Set IV machine, we are talking about deployment in the 1988–89 timeframe as being the target and a range I think can be achieved.

In the case of the Set V machine, which is at a much earlier stage of demonstration and development, current thinking is that that machine can be ready for production in the 1991–92 timeframe.

Mrs. **Bouquard**. Talking about a 2- to 4-year spread?

Dr. **Merriman**. Something on that order. That is subject to some uncertainty, and there are different views from the one I have.

Mrs. **Bouquard**. Thank you.

Dr. **Merriman**. I should note, as already has been mentioned today, that the centrifuge program is a team program. The advanced gas centrifuge effort is a joint effort involving the contractors listed on this chart, which includes the three organizations—Boeing, AiResearch, and Goodyear—who are making Set III machines at the present time.

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DWG. NO. K/G-83-772

AGC PROGRAM STATUS

- SET IV
  - 1.4X ALREADY ACHIEVED (1.5X 1984 DEMO GOAL)
- SET V
  - PROGRAM APPROVED 12/82
  - SPIN TESTS (SHORT SECTION) ACHIEVED EARLY TARGET SPEED GOAL
  - MATERIALS AND SUPPORTING CENTRIFUGE TECHNOLOGY WORK UNDERWAY
  - CENTRIFUGE MANUFACTURERS BUILDING ROTOR SECTIONS – FULL ROTORS WITHIN YEAR

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Chart C

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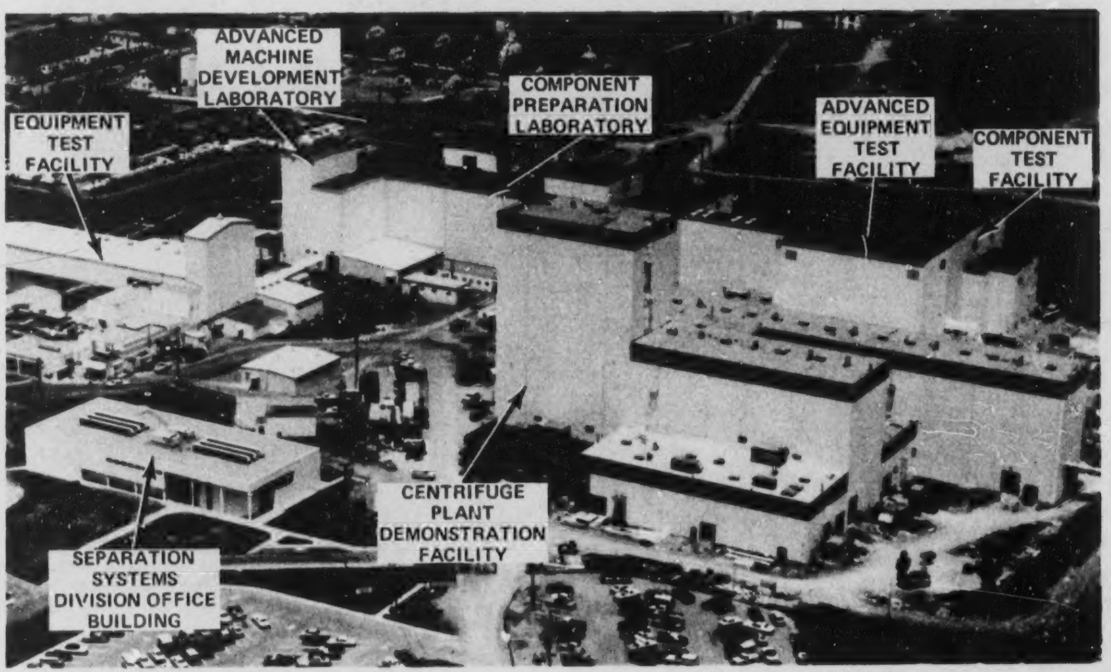
I would like now to summarize the status of this program [chart C was shown]. In the Set IV effort, as Mr. Voigt has already mentioned, we have operated a machine having a capacity 1.4 times greater than the Set III machine, and we are well on the way toward reaching the 1984 goal of 1.5 times greater than the Set III machine. The Set V program, with the new materials was proposed to the DOE in the fall. The program was approved by DOE in December 1982. Spin tests of short sections have achieved the early speed goal which had been set for the program.

There is a significant effort in basic materials and centrifuge technology work needed to support the Set V program. All of the centrifuge manufacturers are building rotor sections and expect to have full-size rotors within a year.

An overview of some of the gas centrifuge development facilities at Oak Ridge, Tenn., is shown here. Similar facilities exist at the other contractor locations. [Chart D was shown.]

DWG. NO. K/G-80-1947

CENTRIFUGE DEVELOPMENT FACILITIES AT OAK RIDGE, TENNESSEE


ADVANCED MACHINE DEVELOPMENT LABORATORY
EQUIPMENT TEST FACILITY
COMPONENT PREPARATION LABORATORY
ADVANCED EQUIPMENT TEST FACILITY
COMPONENT TEST FACILITY
CENTRIFUGE PLANT DEMONSTRATION FACILITY
SEPARATION SYSTEMS DIVISION OFFICE BUILDING

UNION CARBIDE

Chart D

I might take note of one point relating to the status of the centrifuge program, especially the Set III program, because it does relate to questions asked earlier.

The centrifuge manufacturers have invested $100 million in facilities, to manufacture centrifuges. They are currently building set III machines. A centrifuge plant demonstration facility was started up in September of 1982 [chart E was shown]; this facility is the unit cascade, a basic building block cascade, which we will replicate in GCEP.

DWG. NO. K/G-83-680 (PHOTO NO. K/PH-82-3081)

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CPDF-THE CENTRIFUGE PLANT DEMONSTRATION FACILITY

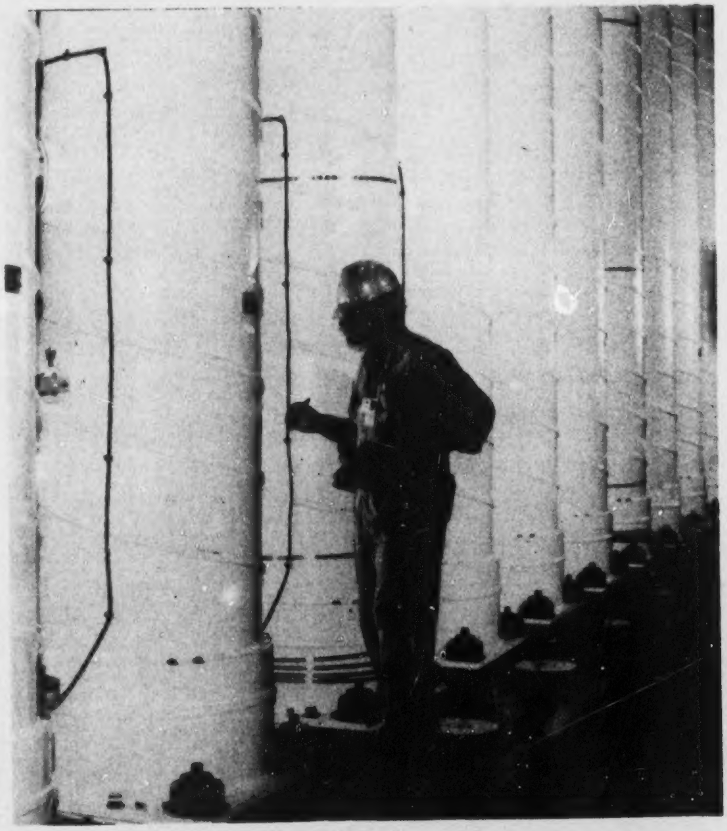

Chart E

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All of the centrifuges and most of the other hardware in CPDF came from the industrial community. The facility is operating well.

The point I would like to make is that the Set III program is a program that is under way at this time. Set III machines are being manufactured. They are working well, and the commercial basis of the Set III machines has been well established.

I would like to turn now to the atomic vapor, laser isotope separation method, that is, the AVLIS program [chart F was shown], three AIS programs pursued by the Department of Energy through the 1970's, the atomic vapor laser isotope separation program was selected by the Department of Energy in April of 1982 for further demonstration.

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DWG. NO. K/G-83-773

AVLIS PROGRAM

- PROCESS SELECTED BY DOE PEB IN APRIL, 1982 IN AIS COMPETITION
- AIS PROGRAM GOAL ⩽ $40/SWU
- JOINT EFFORT
  - LLNL
  - UCC-ND

Chart F

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The evaluation board selected AVLIS on the basis of their judgment that this process had the best potential and least risk in meeting the AIS program goal of achieving a cost of $40 per SWU, as Mr. Voigt mentioned.

This program is a joint effort involving an integrated team, Lawrence Livermore National Laboratory and Union Carbide.

Recently, there have been some significant technical highlights in the AVLIS program summarized here. [Chart G was shown.] Perhaps the most important of these is technical resolution of the thermal control issue cited by the Process Evaluation Board.

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DWG. NO. K/G-83-774

RECENT AVLIS PROGRAM HIGHLIGHTS

- THERMAL CONTROL ISSUE CITED BY PEB HAS BEEN TECHNICALLY RESOLVED
- SIS PROGRAM IS PROVIDING LABORATORY AND LASER FACILITIES APPLICABLE TO URANIUM
- JOINT PLAN FOR ACCELERATED DEMONSTRATION AND DEPLOYMENT OF AVLIS HAS BEEN SUBMITTED TO DOE

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Chart G

A key to early demonstration and deployment of this technology has been provided by the special isotope separation program [SIS] which, as has been noted, is building laboratory and laser facilities at the laboratory.

Considering technical status and progress during the past year and the availability of the SIS facilities, Livermore and Carbide submitted a joint plan to the Department of Energy, which has already been mentioned for accelerated demonstration and deployment of the AVLIS process.

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FEATURES OF PROPOSED AVLIS PLAN

- 1986/1987 PERFORMANCE/COST DEMONSTRATIONS:
  - – FULLY INTEGRATED PROCESS PERFORMANCE AT SCALE — SISL

  SUPPORTED BY
  - – FULLY INTEGRATED MATERIALS HANDLING LIFECYCLE AT SCALE — MHDM
  - – FULLY INTEGRATED LASER LIFECYCLE AT SCALE — HPLF
  - – DETAILED ENGINEERING
- 1991/1992 PRODUCTION; 1–4 MSWU/yr

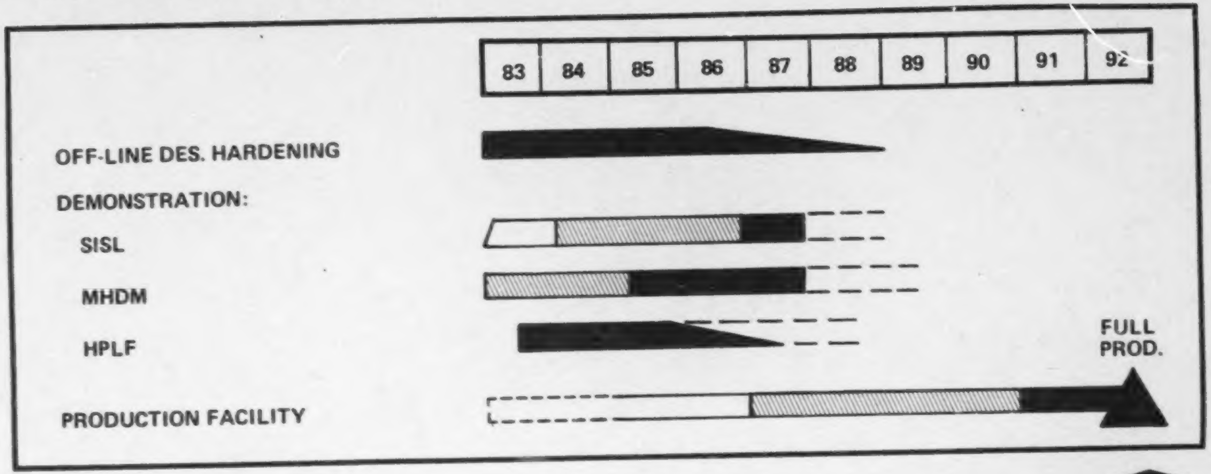

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Chart H

The features of this proposed plan are summarized on this chart. [Chart H was shown.] It calls basically for fully integrated process performance demonstration at the SISL facility. This will be supported by fully integrated materials-handling efforts and demonstrations, laser tests, laser life tests, as well as detailed engineering need to get a good handle on process costs.

On the basis of a successful demonstration and, according to the schedule submitted with the proposal, early deployment in the 1991–92 time frame was recommended as an achievable target.

I would like to convey some feeling of the status of the AVLIS technology by way of illustrating some of the hardware. [Chart I was shown.]

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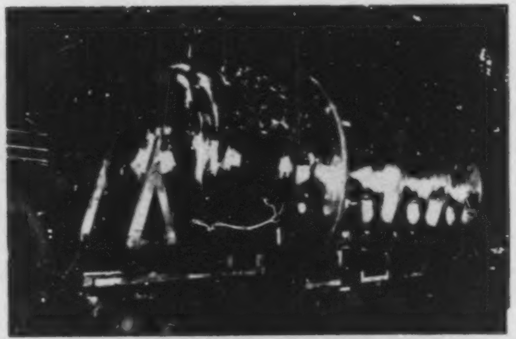
SOME AVLIS FACILITIES

DWG. NO. K/G-83-701



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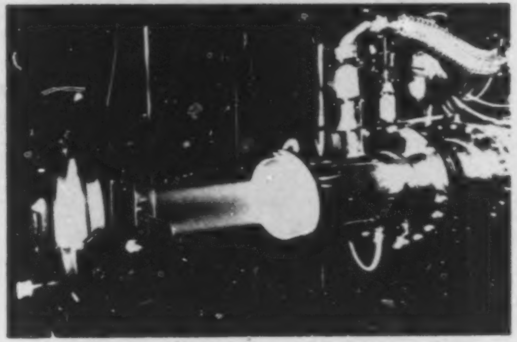

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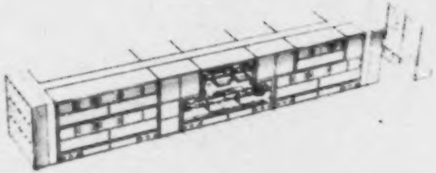

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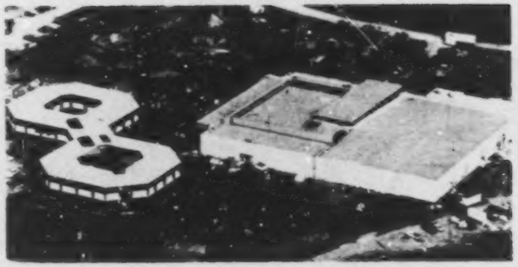

(D)

(A) THE MATERIALS HANDLING DEMONSTRATION MODULE
(B) A PLANT-SCALE COPPER VAPOR LASER
(C) DIAGRAM OF THE HIGH POWER LASER FACILITY
(D) THE SIS LABORATORY

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Chart I

In the upper lefthand corner of this viewchart is the materials-handling demonstration module, MHDM, installed and being activated today at Oak Ridge. This will be the device where the basic uranium-handling technology will be validated and where much of the information needed in the design and activation of the SISL uranium separator and in the determination of material cycling costs will be acquired.

The lower lefthand corner shows a copper vapor laser which is at the power level projected for an AVLIS production plant.

At the upper righthand corner is a diagram of the high-power laser test facility where life test data is being acquired. The lower righthand corner illustrates the construction status of the SIS laboratory as it currently exists.

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DWG. NO. K/G-83-778

SUMMARY

- NO COMPELLING NEED FOR MORE SWUs – NEED CHEAPER SWUs IN 1990's
- AGC (SET V)
  - OFFERS POTENTIAL FOR SIGNIFICANT FURTHER REDUCTION IN GCEP SWU COSTS
  - CONFIDENCE IN MEETING 2X–3X SET V DEMO IN 1986/1987 HIGH
- AVLIS
  - OFFERS POTENTIAL FOR BEING LOWEST COST ENRICHMENT PROCESS IN THE 1990's
  - 1986/1987 DEMO AND 1991/1992 PRODUCTION APPEAR ACHIEVABLE
- NEITHER AGC (SET V) NOR AVLIS IS SUFFICIENTLY DEVELOPED AND DEMONSTRATED TO WARRANT PRODUCTION COMMITMENT TODAY. EXPLOITATION OF THESE TECHNOLOGIES IS, HOWEVER, KEY TO FUTURE ECONOMIC COMPETITIVENESS. THEREFORE, IT IS RECOMMENDED THAT THE AVLIS AND AGC TECHNOLOGY DEMONSTRATIONS BE STRONGLY SUPPORTED AT HIGHEST PRIORITY LEVEL (AFTER PRODUCTION REQUIREMENTS ARE MET).

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Chart J

To sum up [chart J was shown], and again qualifying this as remarks of a technologist, from our viewpoint the primary need is cheaper SWU's for the 1990's. There is no compelling need in our judgment for more SWU's.

I think the advanced gas centrifuge, the Set V centrifuge, offers potential for significant further reduction in SWU costs from GCEP, and I have high confidence in meeting the goal of demonstrating a machine with two to three times the capacity of the Set III machine in the 1986-87 time frame.

As to the AVLIS process, we think it offers potential for being the lowest cost enrichment process in the 1990's.

We believe both the 1986/1987 demo, and if the demonstration is successful, the 1991–92 operation of a phased production facility, appear achievable.

I would like to close by emphasizing that neither the Set V AGC nor AVLIS are sufficiently developed and demonstrated to warrant production commitment today. Exploitation of these technologies is, however, the key to future economic competitiveness of the U.S. enrichment enterprise.

Therefore, I would recommend that these two technology demonstrations, focused on getting good, hard-nosed information in the 1986–87 timeframe, be strongly supported at the highest priority level—of course, after production requirements are met.

Thank you.

[The prepared statement of Dr. Merriman follows:]

Statement of
Robert Merriman
Director, Enrichment Technology
Union Carbide Corporation, Nuclear Division
Before the
Committee on Science and Technology
Subcommittee on Energy Research and Production
U. S. House of Representatives
March 10, 1983

ADVANCED URANIUM ENRICHMENT TECHNOLOGIES

Madam Chairman, members of the Committee, it is a pleasure for me to be here today and describe the advanced technologies the United States is pursuing for uranium enrichment. These are the Advanced Gas Centrifuge (AGC) and Atomic Vapor Laser Isotope Separation (AVLIS) methods. These programs have excellent momentum and potential, and they comprise an important element of the United States' uranium enrichment business.

Looking broadly at the U.S. enrichment activities today, the Gas Centrifuge Enrichment Plant (GCEP) construction project continues to proceed very well. Private industry has now invested over $100 million in centrifuge manufacturing facilities. A new initiative has been taken in the AGC program to begin a major effort to deploy in GCEP high-performance centrifuges made from advanced materials. The AVLIS process was selected for full-scale development and demonstration in the Advanced Isotope Separation (AIS) program competition, and a revised proposal for demonstration and deployment of AVLIS has been submitted. Meanwhile, important cost savings are being realized in the operation of the gaseous diffusion complex via some cost-reduction/productivity improvement programs. These actions are reflected in the recent announcement that there will be no increase for this pricing period in the cost of U.S. enrichment services.

The last several months have seen some significant events in the uranium enrichment business climate as well. The projected demand for U.S. enrichment services has exhibited some additional shrinkage due to continued curtailments in nuclear programs and aggressive competition. In this regard, competition from non-U.S. enrichers, notably Eurodif, has become more intense; and worldwide oversubscription of enriching services has created a secondary market which is adding to the competitive pressures. Today the U.S. enrichment program is fighting loss of market share from strong price competition in an arena where worldwide capacity exceeds projected demand. We understand the U.S. objective to be to protect and, to the extent possible, expand this $2-3 billion/yr U.S. business, one-third of which has a positive impact on our balance of payments picture and which enhances U.S. influence in the nuclear fuel cycle. While we need to ensure long-term flexibility to respond to shifts in requirements, our current focus is not so much on more SWUs for the 1990s, as it was in the mid-1970s when the gaseous diffusion capacity expansion was under way and GCEP was started, but on cheaper SWUs for the 1990s. We are concerned that we cannot remain competitive in the marketplace so long as our production is exclusively provided by energy-intensive gaseous diffusion plants.

Therefore, we see the DOE program being geared toward displacing gaseous diffusion capacity with more cost-effective production methods. Our major tools in this competition are the traditional ones where the U.S. enrichment program has always excelled: advanced uranium enrichment technologies. Today there are two very attractive technologies--AGC and AVLIS.

I am pleased to have this opportunity to describe the AGC and AVLIS programs for you. As requested, I will summarize the status and potential of the technologies, outline the programs, briefly note the economic incentives as we see them today, and describe how the advanced technologies, once demonstrated, might be deployed so that SWU costs in the 1990s can be signficantly reduced.

THE ADVANCED GAS CENTRIFUGE PROGRAM

The objective of the AGC program is to develop, demonstrate, and deploy machines having separative capacities well above that of the initial Gas Centrifuge Enrichment Plant (GCEP) machine on a schedule which will permit their use in GCEP to achieve a reduction in U.S. SWU costs. The initial GCEP machine, the Set III machine, represents a demonstrated technology, which was targeted to be more economic than gaseous diffusion when deployed on a commercial scale. While the purpose of this statement is to summarize the AGC and AVLIS programs, a brief comment on the status of the Set III machine will provide a useful point of departure.

The gas centrifuge program achieved a major milestone in September 1982, when the Centrifuge Plant Demonstration Facility (CPDF) was placed in operation in Oak Ridge. The CPDF is a unit cascade of Set III machines which will be replicated many times in GCEP; i.e., it is the basic GCEP building block. All of the machines and most of the other hardware were procured from industrial firms. Since the start-up, cascade operation has been continuous with only short interruptions. To date, the cascade has operated above the GCEP design levels of performance and availability. The reliabilities of the cascade and the machines have so far exceeded the expectations projected for the Portsmouth plant. This accomplishment confirms the commercial readiness of the centrifuge machine and plant equipment and of the industrial manufacturing capability. A view of the CPDF cascade is shown in Chart 1. The CPDF is operating well, providing important data, and producing SWUs.

The key component of a gas centrifuge is its rotor. In general, separative capacity is increased and the cost of SWUs is decreased by building long rotors and spinning them as fast as possible. Practically speaking, the length is limited by the ability to balance and stably operate high-speed machines which pass through flexural criticals as they are driven up to operating speed. The speed is limited by materials physical properties, coupled with design/manufacturing practicalities.

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CPDF-THE CENTRIFUGE PLANT DEMONSTRATION FACILITY

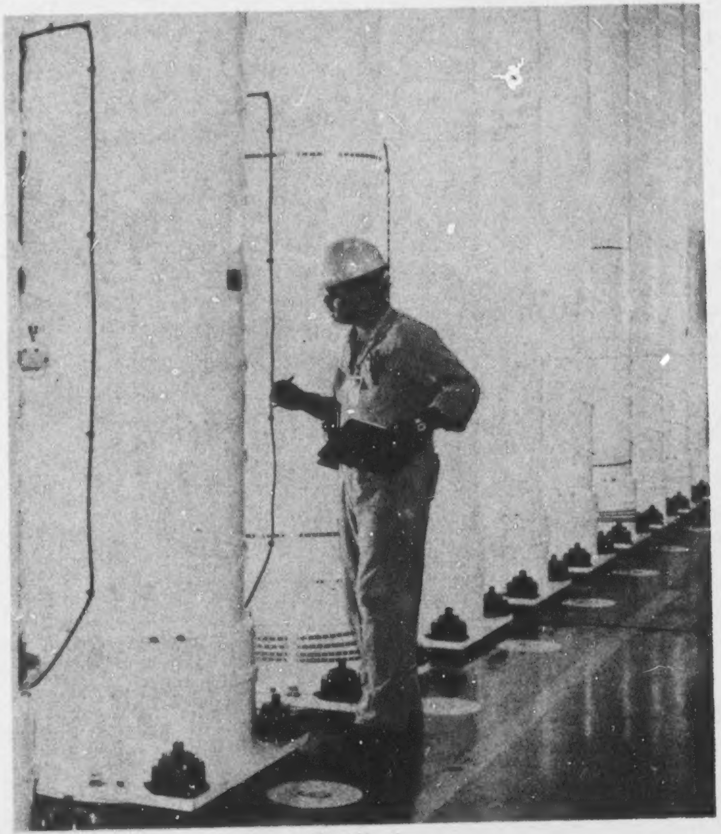

Chart No. 1

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The two primary objectives of the AGC program are to exploit the potential capabilities of the current GCEP rotor material and of advanced materials:

1. One objective is to operate in 1983, and thoroughly demonstrate in 1984, a machine design (Set IV) which has a capacity of 1.5 times that of the Set III machine.

2. A second objective is to demonstrate in the 1986/1987 time frame a machine (Set V) which has a capacity of two to three times that of the Set III machine. This machine will employ advanced materials. An in-depth technical and economic assessment of this program in 1984 will be used to reevaluate this objective and to help define the most advantageous deployment scenario for the Set V machines.

These machines are being designed to be used in GCEP as initial fill and/or retrofit units.

The AGC program is a joint effort involving the entire U.S. centrifuge development/commercialization community, i.e., Union Carbide Corporation, Nuclear Division (UCC-ND), the University of Virginia (UVa), Boeing Engineering and Construction Southeast, Inc. (BECSI), Goodyear Aerospace Corporation (GAC), AiResearch Manufacturing Company (AMC), and Electro-Nucleonics, Inc (ENI). These organizations all have many years of experience in the gas centrifuge program. UCC-ND has been selected by DOE as the lead contractor for the AGC technical effort and as the AGC machine design integrator.

Set IV Program

The primary thrust of the Set IV program is to take full advantage of the capability of the current rotor material mainly by increasing the speed. Machines have already operated at 1.4 times the Set III performance level. The dynamic behavior and balance of the Set IV rotors already tested have been satisfactory.

We are well into the concept demonstration phase of the program and are essentially at the point where the final geometry and features of the Set IV machine will be chosen and integrated into a design package for use in fabricating the design verification machines for the Set IV demonstration in 1984. The next step toward deployment of Set IV machines would be reliability testing, which is scheduled to begin in 1985.

In summary, significant progress has been made in achieving the Set IV performance target, and the program is progressing well as it moves into the demonstration phase. Because of the substantial experience with rotors of this type, there is high confidence in the success of the Set IV effort.

Set V Program

Advanced materials which are now available offer the potential for significantly improving the performance of gas centrifuges. Recognizing this potential, UCC-ND, AMC, BECSI, GAC, and UVa submitted a joint program proposal directed toward exploiting this potential to DOE in September 1982. This proposal is based on the consensus judgment that " . . . these are the materials of the future for the centrifuge." Key elements of the proposal are a strong, aggressive basic materials technology and advanced centrifuge machine technology effort by UCC-ND in concert with parallel development of alternative rotor manufacturing techniques by the three centrifuge manufacturers. Key milestones include verifying the basic potential of achieving target speeds in 1983 (which has been accomplished), building and operating both short- and full-sized rotors manufactured using different candidate approaches in 1983 and 1984, acquiring sufficient technical and performance information by 1984 to permit an in-depth assessment of deployment potential and options, and demonstration of Set V machines in the 1986/1987 time frame.

In December 1982, DOE approved the program. Good progress is already being made by each participant. While the development program will be technically challenging, especially during the next 2 yr, the potential benefits justify the effort, and confidence in a successful Set V demonstration in 1986/1987 is high.

THE ATOMIC VAPOR LASER ISOTOPE SEPARATION PROGRAM

The objective of the AVLIS program is development, demonstration, and deployment of a version of this technology capable of meeting the DOE AIS program target of providing process costs $\leq$\$40/SWU. AVLIS was one of three AIS processes pursued competitively by DOE in the 1970s. In April 1982, AVLIS was selected by the DOE Process Evaluation Board (PEB) as having the best potential for and least risk in meeting the AIS program objectives. The high selectivity of AVLIS distinguishes it fundamentally from either the gaseous diffusion or gas centrifuge process. The use of uranium rather than UF_6 as the process working medium is, of course, another difference.

The AVLIS program is being implemented by an integrated joint team comprised of representatives from the Lawrence Livermore National Laboratory (LLNL) and UCC-ND. LLNL is currently the lead laboratory. These two organizations have collaborated on AVLIS development since the inception of the program in the mid-1970s.

The two major hardware assemblies of the AVLIS process are the separator and laser subsystems. Independent development and demonstration facilities for each of these subsystems are now reaching the point where work is proceeding or can soon proceed on production scale systems. Chart 2 illustrates some of the key separator and laser systems and facilities now in the program.

In selecting AVLIS, the DOE PEB stated that " . . . there is reasonable probability that the AVLIS process can achieve enrichment costs at less

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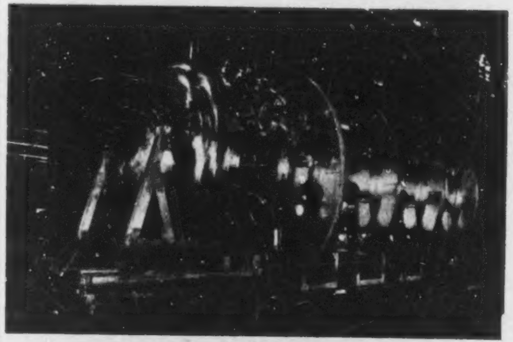
SOME AVLIS FACILITIES



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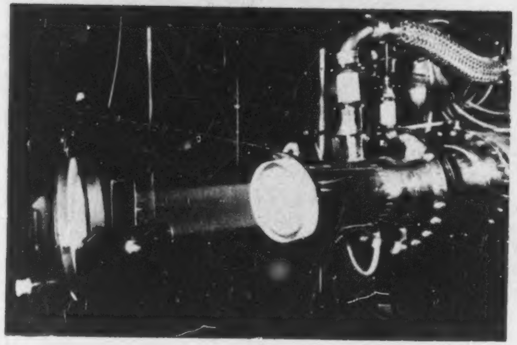

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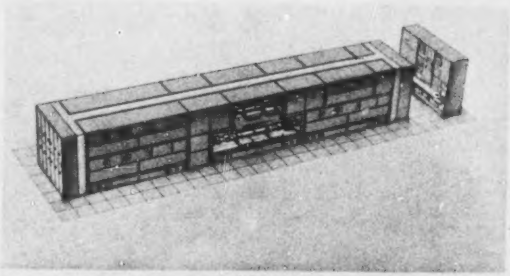

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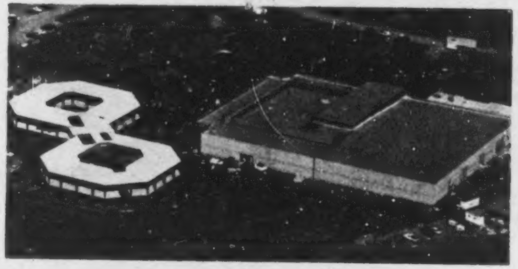

(D)

(A) THE MATERIALS HANDLING DEMONSTRATION MODULE
(B) A PLANT-SCALE COPPER VAPOR LASER
(C) DIAGRAM OF THE HIGH POWER LASER FACILITY
(D) THE SIS LABORATORY

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Chart No. 2

than the economic goals set for the AIS program," but noted a significant concern with " . . . the thermal control performance of the liquid uranium collector." Since process selection, significant progress has been made in resolving the thermal control issue. Also, advances in laser technology and engineering have continued. In addition, AVLIS is being supported within the defense program area for Special Isotope Separation (SIS). Included in the SIS program is construction of a laboratory facility at Livermore (SISL) and the funding of lasers, both of which have basic applicability to uranium isotope separation.

Considering these factors, in January 1983, LLNL and UCC-ND submitted a joint proposal to DOE for rapid demonstration and deployment of AVLIS.

The previous AVLIS program plan was based on the construction of a Development and Demonstration Module (DDM) beginning in FY 1984, with full-scale demonstration and engineering technology confirmation scheduled for 1990. The new proposal combines the most important engineering design features from the DDM in SISL, which is now under construction, to perform technology and engineering demonstration by the 1986/1987 time frame, which is about 3 yr earlier than in the previous plan. The SISL demonstration will be roughly equivalent from a technical standpoint to the demonstration that would have been done in the DDM. In combination with off-line life tests and subsystem prototype facilities and with the detailed production plant engineering design which is also planned, (beginning now with conceptual studies for the next 2 yr and progressing then to formal detailed design), this demonstration will confirm technology performance and establish associated economic parameters, permitting a good deployment decision. The detailed production facility design will not only help guide the technical efforts and provide the necessary cost information but would also expedite deployment.

To sum up, the key AVLIS milestone in the recently proposed program is a process demonstration using production scale hardware which is accompanied by a good engineering basis in 1986/1987. This demonstration package, if successful, could give DOE the opportunity to deploy AVLIS in the early 1990s. We believe these goals are achievable, and that the benefits justify the proposed effort.

POTENTIAL ECONOMIC IMPACTS OF AGC AND AVLIS

Both the AGC and AVLIS programs are pointed toward significant technical demonstrations and detailed economic evaluations in the 1986/1987 period. This will enable decisions about deployment of either (or both) of these advanced processes. In looking ahead, it is useful to consider the economic incentives for these new technologies, to help guide our programs and our allocation of resources.

Present gaseous diffusion costs are on the order of $100/SWU, most of which reflect electric energy costs. (Present U.S. SWU prices are ~$140 to 150/SWU since other items, such as imputed interest on stockpiles and construction funds, are included.) With significant competition in the

$100 to 125/SWU range, the benefits of the advanced technologies seem evident. We believe that the AGC and AVLIS technologies offer the potential of cutting our costs by a factor of 2 to 3, relative to gaseous diffusion, and this provides a good basis, we think, for their emphasis. The U.S. program, therefore, is faced with achieving a transition from gaseous diffusion production to more cost effective processes. The present DOE program includes emphasis on cost reduction in gaseous diffusion operation, phasing in of GCEP, and demonstration of AGC and AVLIS. This is potentially the most powerful competitive package in the world, but care must be taken in managing the transition. This will require, in my view, continuing an open, constructive, cooperative effort by the technologists, industry, the Administration, and the Congress. It would not be prudent to shut down gaseous diffusion plants until sufficient operational experience is gained with the "next" process. Similarly, it would not be prudent to stop the present GCEP project without a hard-nosed demonstration of AGC and/or AVLIS of the types proposed in those two program plans. On the other hand, it would also be unwise to put such low emphasis on AGC and AVLIS that their potential impact in the marketplace is preempted. We are fortunate to have an opportunity to make good decisions now since there is no compelling market situation which is currently driving us toward more capacity.

SUMMARY

In this very complex picture, which will require continuing evaluation over the next several years, there are no simple answers. In this vein, the following concluding comments are offered:

1. Heavy competition in a reduced SWU market emphasizes the need to assure low-cost SWU production for the 1990s, not necessarily more SWUs. The current market situation does not compel us to add new capacity, so that there is an opportunity to evaluate all our options carefully.

2. The gaseous diffusion process represents a solid, reliable technology, but its high demand for power makes it less economically attractive for the longer term. The transition away from gaseous diffusion should, however, be a deliberate one.

3. The ability to install and to retrofit improved centrifuges in GCEP enhances its economic attractiveness. Gas centrifuge technology has significant potential for improvement which can be exploited in this manner. GCEP, with a full complement of Set IV machines, will result in a long-term reduction in SWU cost relative to gaseous diffusion. For these reasons, construction of GCEP should be continued in a manner which preserves a good capability to continue to deploy advanced gas centrifuges.

4. The Set V AGC, if deployed in GCEP, appears now to offer potential for reducing even further the cost of SWUs from GCEP. Accordingly, the AGC development and demonstration program should continue to be fully supported. To the extent possible, near-term GCEP project

decisions should be made that will leave open the option of rapid AGC deployment if warranted on the basis of the planned 1986/1987 Set V demonstration.

5. Although the AVLIS process is at an earlier stage than the gas centrifuge, it appears to offer the best potential for further reducing SWU prices in the 1990s if successfully demonstrated. Fundamentally, we believe that this process, when demonstrated and deployed, will not be matched by our competitors in this century. Therefore, the AVLIS demonstration program, including both the SISL performance demonstration and the detailed production plant engineering design necessary to establish process economics and expedite deployment, should be fully supported.

6. Neither AGC (Set V) nor AVLIS is sufficiently developed and demonstrated at this time to warrant commitment to production. However, both the AGC and the AVLIS technology development programs are structured to emphasize obtaining sufficient key technology evaluation data by the 1986/1987 period to allow a firm assessment of their real-world performance capabilities and attractiveness for production use in the early 1990s. The data acquired in the next few years will provide the bases for choosing between the two technologies and for directing emphasis to provide the lowest practical SWU prices in the early 1990s. We believe the key to cost effective, competitive enrichment in the 1990s and beyond lies in the exploitation of our advanced enrichment technologies. Therefore, it is important that these efforts be very strongly supported at least through the 1986/1987 demonstration.

ROBERT MERRIMAN

Director of Enrichment Technology
Union Carbide Corporation, Nuclear Division

Robert Merriman was born in Knoxville, Tennessee, in 1941. He received his B.S. degree in chemical engineering in 1963 from Vanderbilt University, and his M.S. (1966) and Ph.D. (1975) degrees in the same field from the University of Tennessee.

Dr. Merriman began his career in 1963 with Union Carbide Corporation, Nuclear Division, at the Oak Ridge Gaseous Diffusion Plant. He has held several positions, including Development Engineer (1963) and Chemical Process Development Section Head (1968) at Oak Ridge; Superintendent of the Planning and Technical Support Division (1972), Manager of the Plant Engineering Division (1974), and Manager of Engineering and Technical Services (1976) at the Paducah Gaseous Diffusion Plant; and Director of the Enrichment Technology Division at Oak Ridge (1977). He was appointed to his present position in 1981 and is responsible for Union Carbide's activities in support of DOE programs in development and technical support for the gaseous diffusion, gas centrifuge, and atomic vapor laser isotope separation processes.

He has been involved in a variety of chemical process development activities related to isotope separation, nuclear fuel reprocessing, nuclear waste disposal, and special material production. He is a recipient of the University of Tennessee Outstanding Engineering Alumnus Award (1979). He is a member of Tau Beta Pi and of the American Institute of Chemical Engineers.

Mrs. BOUQUARD. Thank you very much, Mr. Merriman. Your presentation was very constructive.

How do we stand on costs and what risks are we calculating in the atomic vapor laser isotope separation process?

Dr. MERRIMAN. I can only provide a general sort of answer which I hope will be acceptable, since the risk in any new venture is hard to quantify, and say that in present plans proposed to DOE an effort was made to assess risk and appropriately balance these risks and the opportunities.

I think the schedule, which is part of your question, is on a fast track commensurate with the value associated with our early deployment of the low-cost process. By fast track, I mean key activities are pursued in parallel: closely coupled, off-line demonstrations, for example, which provide key information to designs of other facilities.

This is, of course, a fairly normal approach for programs of this type. I think such a program does require timely decisions, timely availability of resources, and tight management. In this kind of effort there are risks of schedule slippages.

As regards the point about reliability, I would say that the basic system architecture selected for the atomic vapor laser isotope separation and the modular approach to the components do facilitate the scale-up and the achievement of availability targets which would be economic. We think that plant availability targets can be achieved with component lifetimes which can be demonstrated in the near future.

For example, based on the current assessment, it appears that the component having the highest lifetime need is the copper vapor laser, and its lifetime has to be on the order of a few thousand hours.

Today, in the near future, it is expected that lifetimes on the order of 1,000 hours will be demonstrated.

As regards the cost, I might point out that during the AIS selection process an associated very intensive peer review went on, in which the impacts of those uncertainties in cost, performance, physics, and so forth, were very, very carefully debated in this intense period of evaluation.

This led to a conclusion that a $20-to-$40-per-SWU range was possible, even assuming risks identified by the competing laboratories.

While there certainly will be challenges in achieving the targets we have cited, I still believe this is a credible potential of the atomic vapor laser isotope separation capability if it is successfully demonstrated.

In our judgment, considering the risk, both the $20-to-$40-per-SWU projection and the ability to demonstrate the process in the 1986–87 timeframe appear to be realistic goals.

Mrs. BOUQUARD. Since the riding force is now competition, since we no longer have a corner on the market we had at one time, what sort of work are other nations against which we will compete doing on the advanced isotope separation and advanced gas centrifuge technologies? How competitive are our competitors at this point?

Dr. **Merriman**. Let me summarize in this fashion: I believe that in both the centrifuge area and the laser isotope separation area the advanced technologies being pursued by the United States are the best in the world.

I should add that other nations, and perhaps more details can be provided later, are energetically pursuing centrifuges and——

Mrs. **Bouquard**. I don't want to get into anything we will cover in the next session.

Dr. **Merriman**. All right. Perhaps I can give a better answer then.

Mrs. **Bouquard**. We will defer that.

Mr. Ottinger?

Mr. **Ottinger**. Dr. Merriman, suppose we said to the Department of Energy they should hold back on the Set III deployment and accelerate activities relative to the Set IV machines. How soon do you think Set IV machines would be ready for deployment and how much would that acceleration cost and how much of an acceleration can you achieve?

Dr. **Merriman**. There are a number of options even within the Set IV program which are part of the detailed evaluation that Mr. Voigt has mentioned earlier. There are opportunities for selections of designs which might permit a little faster deployment.

While a final answer should await the results of the study, my view is that 1988-89, which represents a possible year or so advance, is feasible under certain assumptions as to which design alternative is selected and when we decide to move.

I do not see more than, say, a year nominally being cut from that schedule.

Mr. **Ottinger**. On your chart you said you already achieved 1.4 times and you anticipate shortly to get 1.5 times. What does that mean? That means you can build a machine now at 1.4?

Dr. **Merriman**. The quick answer is that one possible approach to introducing Set IV machines earlier is to go ahead and decide to build machines close to the kinds of machines that are demonstrated at 1.4 times and perhaps moving quicker with that machine as opposed to taking a longer period of time to gain the——

Mr. **Ottinger**. How long would it take to produce machines at 1.4 times what you have now? You can furnish that information later if you do not have it now.

Dr. **Merriman**. Again, at this stage I would like to stand with the comments I made when presenting the Vu-Graph earlier.

Mr. **Ottinger**. You mentioned companies, yours is one, that have $100 million invested in Set III machines. Is that the motivation for not moving faster on Set IV? Wouldn't the companies get their money?

Dr. **Merriman**. My company, Union Carbide, does not have money invested. We are an operating contractor for DOE.

Mr. **Ottinger**. You get paid one way or the other?

Dr. **Merriman**. There would be some—in fact, however, I do not know the amount of the payment.

At any rate, the investment, the significant investment, seriously, is that which has been made by Boeing, Goodyear, and AiResearch Manufacturing Co.

Mr. OTTINGER. They get that whether we proceed or not, do they not?

Dr. MERRIMAN. I am not familiar with the terms of their contract with DOE.

Mr. OTTINGER. Turning to the atomic vapor laser isotape separation, you have an accelerated schedule there which indicates, am I correct, that it might be operational in the 1987, or 1986–87 timeframe?

Dr. MERRIMAN. The goal we recommended to the Department of Energy is a full plant scale, fully integrated demonstration in the 1986–87 timeframe. That is not a production unit. It will mimic a production unit to the extent of allowing us to provide a real hard-nosed evaluation of the economics of the process.

Mr. OTTINGER. A commercial scale pilot or smaller?

Dr. MERRIMAN. Full sized.

Mr. OTTINGER. It will be full sized?

Dr. MERRIMAN. Yes.

Mr. OTTINGER. If it works, it can be used?

Dr. MERRIMAN. Again, perhaps I can give a better feeling of what that demonstration is. It is not a production unit and there are no plans to use it as a commercial project. It is a demonstration. It will not have everything a production plant will have. It will demonstrate technology at full scale.

Mr. OTTINGER. Can you add whatever you need to make it a production facility?

Dr. MERRIMAN. The concept is that full-size hardware would, in fact, be replicated and engineered and would be used in the production.

Mr. OTTINGER. Actual equipment used in the test cannot be used?

Dr. MERRIMAN. I am hedging on that because it is difficult. I would say it would not be the right thing to do because the SISL demonstration facilities will become the primary program test bed following the period of the demonstration. There will need to continue to be significant technical effort to support the primary effort aimed at constructing and operating the production plant.

Also one of the most important hedges against cost growth and performance shortfalls in any technology is to continue to have a demonstration and development capability.

Mr. OTTINGER. What would the cost of these demonstration models be; do you know?

Dr. MERRIMAN. The proposed program cost to the uranium enrichment program is approximately $300 million through the 1986–87 demonstration.

Mr. OTTINGER. How is that cost shared?

Dr. MERRIMAN. In addition to that, there is approximately $150 million that is being provided by the SIS program. That is not the total SIS effort but it is that fraction applicable here.

Mr. OTTINGER. What would be the reason for going ahead with the Set III machines if, in fact, they will produce material at uncompetitive prices even though a substantial investment has been made?

Dr. MERRIMAN. That is certainly a good question and it is one that I am sure is being considered by those responsible for policy, which fortunately I am not.

I would offer one comment; namely, we do have, and the success of the centrifuge as an option for enriching uranium depends upon, the industrial base which has now been created and is functioning. To stop that, in my view, will foreclose the centrifuge option.

Mr. OTTINGER. Explain that to me a little more. Why would not the industrial base be involved in the Set IV machine?

Dr. MERRIMAN. I think if your question is the use of that industrial base to perhaps spend more effort in helping build and demonstrate Set V machines and perhaps emphasizing more than we are today Set IV machines, and therefore concurrently reducing the expected construction rate of Set III machines, that is a scenario which has some merit.

Again, my personal opinion is that there might well be merit in not ramping up so fast in the construction of Set III machines and working aggressively on Set V.

However, I would emphasize that establishing a lower limit for the rate at which Set III machines are built is a determination which needs to be carefully considered in terms of protecting the ability to manufacture centrifuges of any type.

Mr. OTTINGER. Thank you.

Mrs. BOUQUARD. Mr. Winn?

Mr. WINN. Thank you, Madam Chairman.

Before I forget it, you invited Congressman McEwen, from Ohio, to participate in the hearings. Even though he is unable to attend today, I would like to ask unanimous consent to have a series of questions he submitted for both Mr. Voigt and Mr. Merriman sent to them so they can answer them.

Mrs. BOUQUARD. Without objection, the questions will be submitted.

Mr. WINN. Thank you very much.

Mr. Merriman, this may be hard for me to grasp because I am not a technician. I cannot figure out what the primary technical impediments to the successful development of Set V advanced gas centrifuge machine might be. Can you explain it to a novice?

Dr. MERRIMAN. It is difficult to answer that without getting into classified information. You can say generally it is development of a manufacturing technique and use of advanced material.

Mr. WINN. I will defer that question until later.

I had a question here that I wanted to ask of Mr. Voigt, but I can ask it of you because I think it is down your alley. This has to do with providing for the record an unclassified version of the recent proposal by Lawrence Livermore Laboratory to accelerate the AVLIS program.

Can you tell us the reason for that? That was a joint decision, I think, between the lab and the Union Carbide to accelerate that pace. Can you elaborate on that a little bit?

Dr. MERRIMAN. Yes. I would be happy to provide a copy of the proposal for the record.

[The material referred to follows:]

UNION CARBIDE

MISC 4100

PROPOSAL
FOR
EARLY AVLIS DEMONSTRATION AND PRODUCTION*†

Presented to

William R. Voigt, Jr.

Deputy Assistant Secretary for
Uranium Enrichment and Assessment

January 11, 1983

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*This document is an unclassified version of original presentation.

February 11, 1983

†Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under Contract W-7405-Eng-48.

OUTLINE OF BRIEFING

- Introduction
- The Proposal
- Critique and Response
- Conclusions

U. S. URANIUM ENRICHMENT – KEY ISSUES

- U.S. is losing its competitive edge.
  - High SWU costs
  - Aggressive foreign competition
- Development and implementation of new low cost capacity is difficult to fund adequately.

AVLIS PROGRAM CAN IMPROVE U.S. ENRICHMENT POSITION

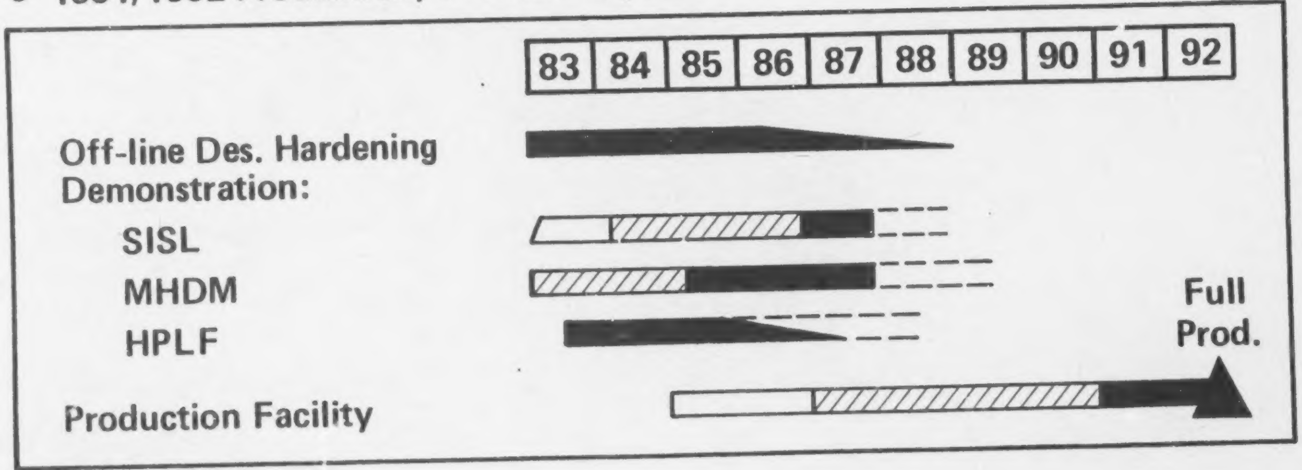
- Low Capital Cost
  - Low capital risk in uncertain market
  - Short lead time for implementation
- Low SWU Cost
  - Price below forward cost of foreign competition
  - Increased demand for SWU capacity
  - Added value to U.S. tails stockpile
- Ability to Meet Additional Missions
  - E.g., U^{235} – U^{236} recycle

FEATURES OF PROPOSED AVLIS PLAN

- 1986/1987 Performance/Cost Demonstrations:

— Fully integrated process performance at scale	SISL
Supported by	
— Fully integrated materials handling lifecycle at scale	MHDM
— Fully integrated laser lifecycle at scale	HPLF

- 1991/1992 Production; 1-4 MSWU/yr



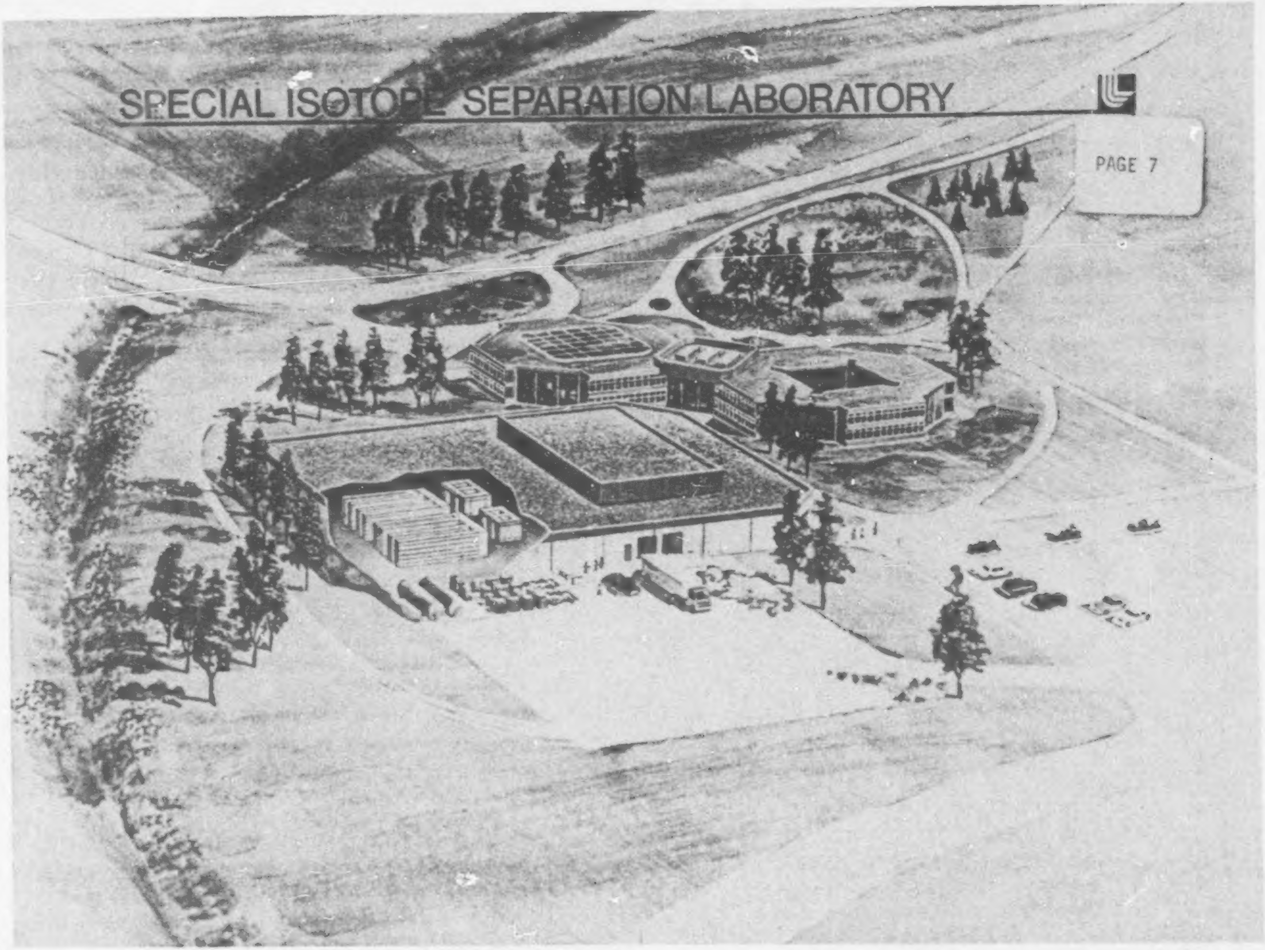
70-01-0183-0059

CRITERIA FOR 1986/1987 DEMONSTRATION

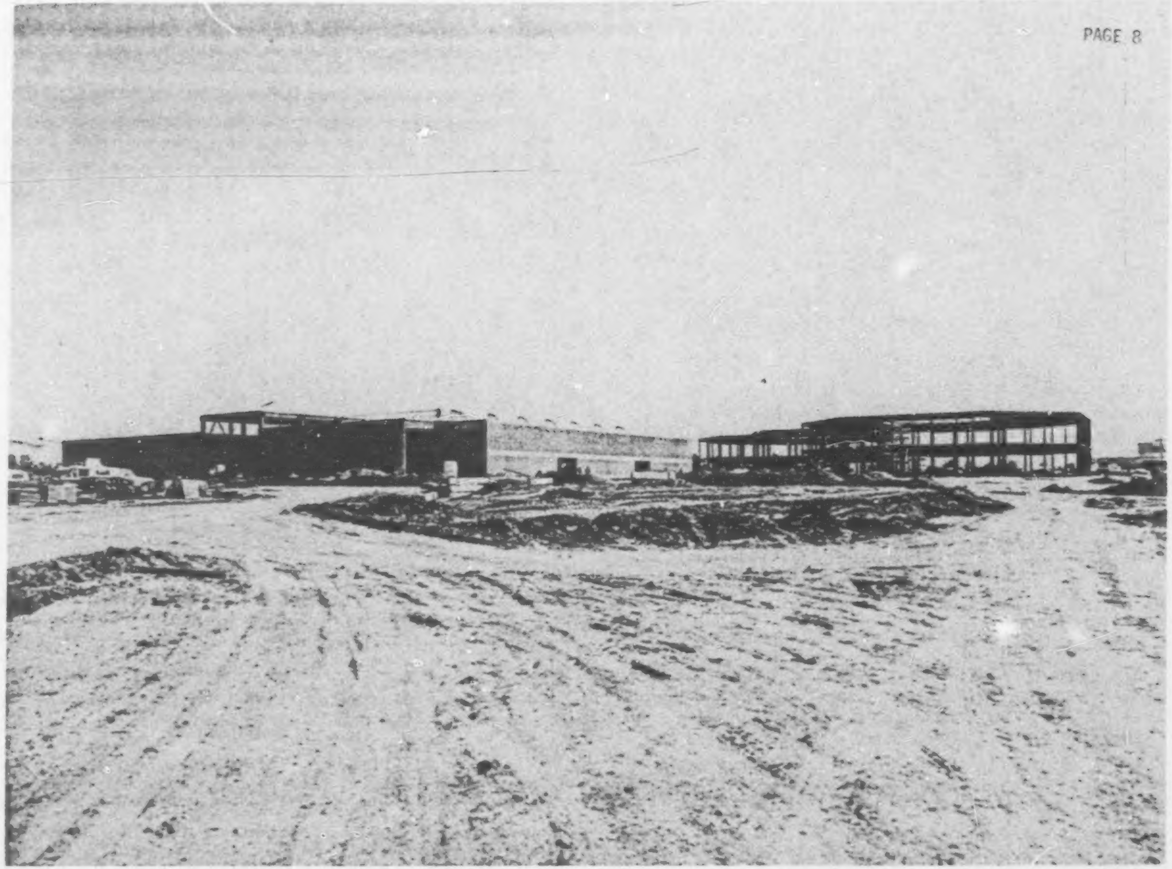
MUST PROVIDE BASIS FOR CONSTRUCTION START ON PRODUCTION FACILITY IN 1987

- PERFORMANCE: Conclusive demonstration of separative performance:
  - SWU/kg, determines size of material processing system.
  - SWU/J, determines size of laser system.
- CAPITAL: Complete documentation of total process capital cost:
  - Actual components and subsystems costs for demonstration system must be less than 3X that for production system.
  - Production Facility Title I & II design will bound capital cost to within 20 percent.
- OPERATING: Complete documentation of operating procedures and costs:
  - Actual component maintenance cycle costs for demonstration system must be less than 3X that for production system.
  - Existing facilities must provide basis for continued improvement of component lifetime, operating procedures, and training of personnel for production facility.

With the exception of complete lifecycle operating experience, the 1986/1987 demonstration will bound the cost to within 3X of our production cost goal ~20$/SWU



SPECIAL ISOTOPE SEPARATION LABORATORY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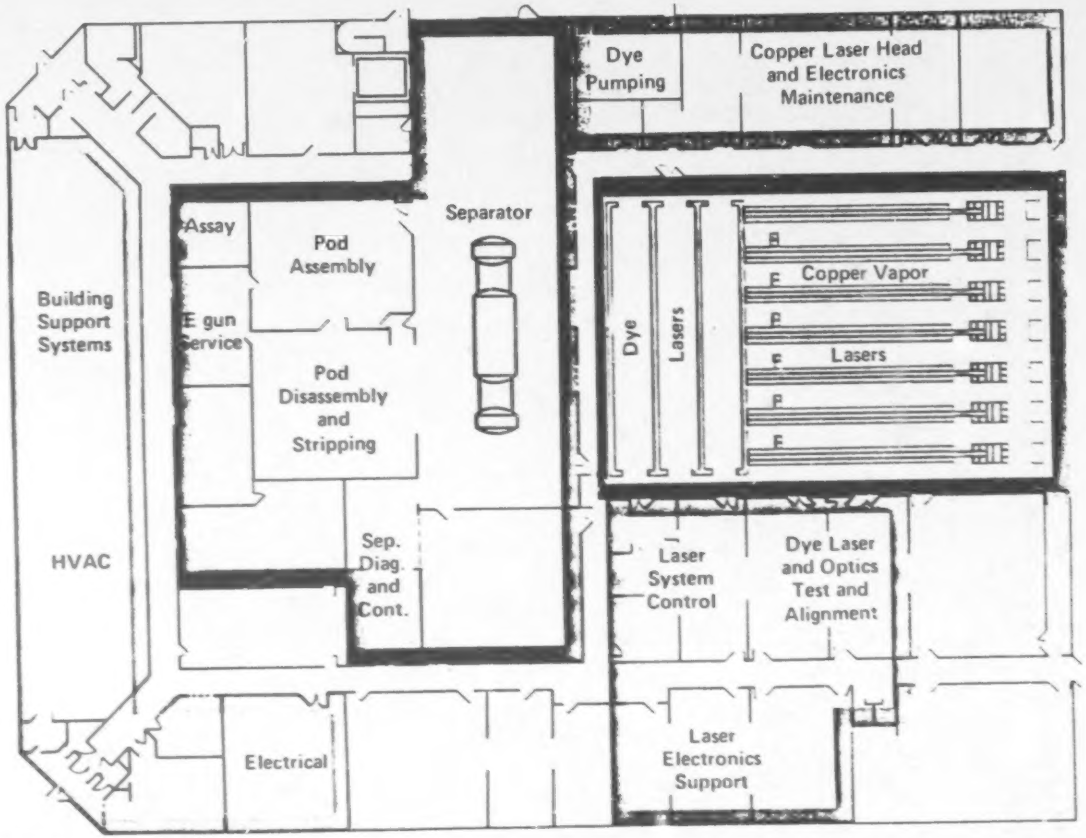
SISL FACILITY FOOTPRINT


Dye
Pumping
Copper Laser Head
and Electronics
Maintenance
Separator
Assay
Pod
Assembly
E gun
Service
Pod
Disassembly
and
Stripping
Building
Support
Systems
HVAC
Sep.
Diag.
and
Cont.
Dye
Lasers
Copper Vapor
Lasers
Laser
System
Control
Dye Laser
and Optics
Test and
Alignment
Laser
Electronics
Support
Electrical

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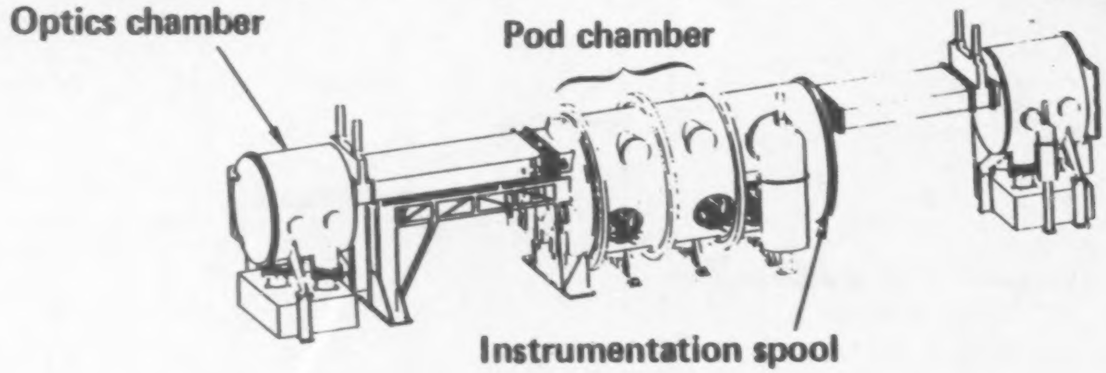
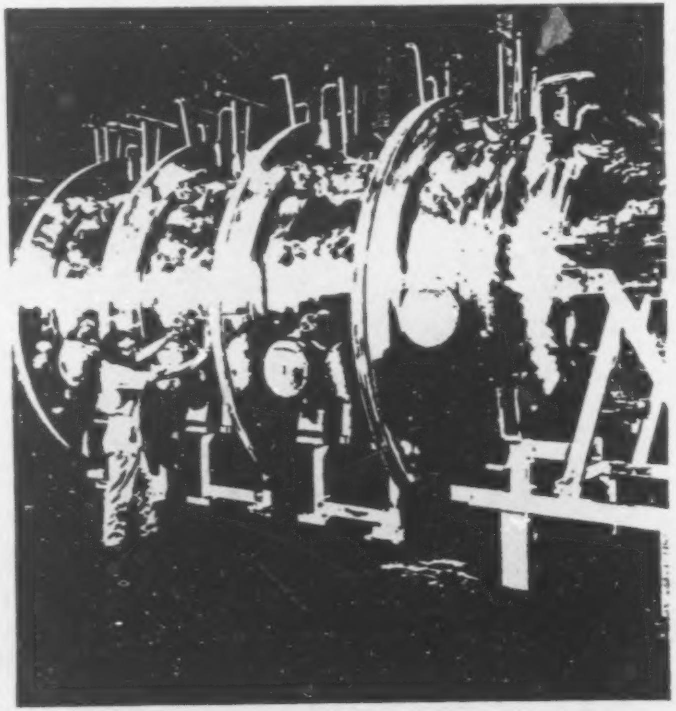
SISL SEPARATOR


Optics chamber
Pod chamber
Instrumentation spool

Goal: To provide a conclusive demonstration of AVLIS enrichment performance

- One full scale pod
- Production SWU/kg: multicell illumination
- Production SWU/J; full array illumination
- Mass balance evaluation
- → In design

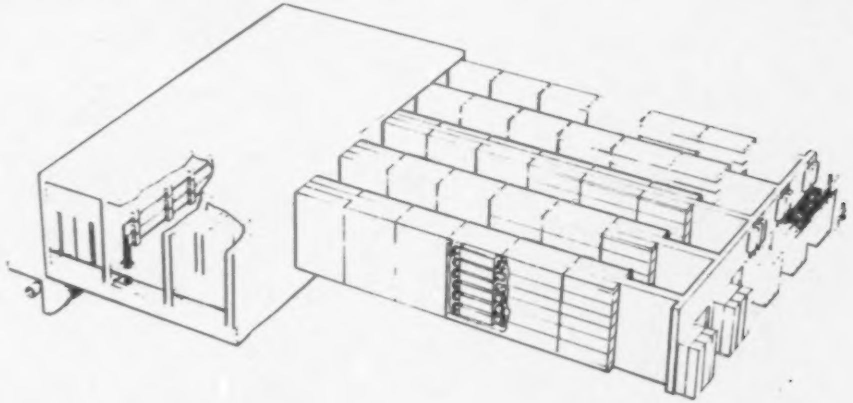
MHDM – MATERIALS HANDLING DEMONSTRATION MODULE



Goal: To supply materials handling life cycle and cost data.

- Full liquid flow characterization
- Maintenance cycle development and optimization
- → In installation and activation

SISL LASER SUBSYSTEM



Goal: To provide ~ 1000 W tunable for enrichment demonstration

- Production prototypical laser system
- ~ 100 full scale copper vapor lasers
- Full scale dye laser demonstration
- Configuration, maintenance and operations development and optimization
- → In design

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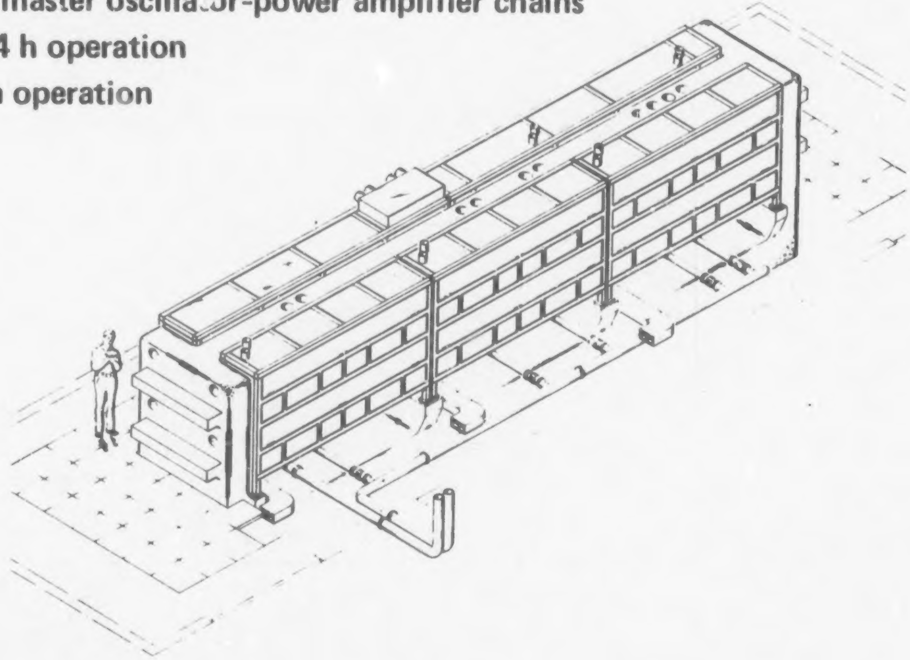
HPLF – HIGH POWER LASER FACILITY

Goal: To supply lifetime data for copper vapor laser heads and electronics

- 8 large bore copper lasers
- 2 master oscillator-power amplifier chains
- 24 h operation
- → In operation



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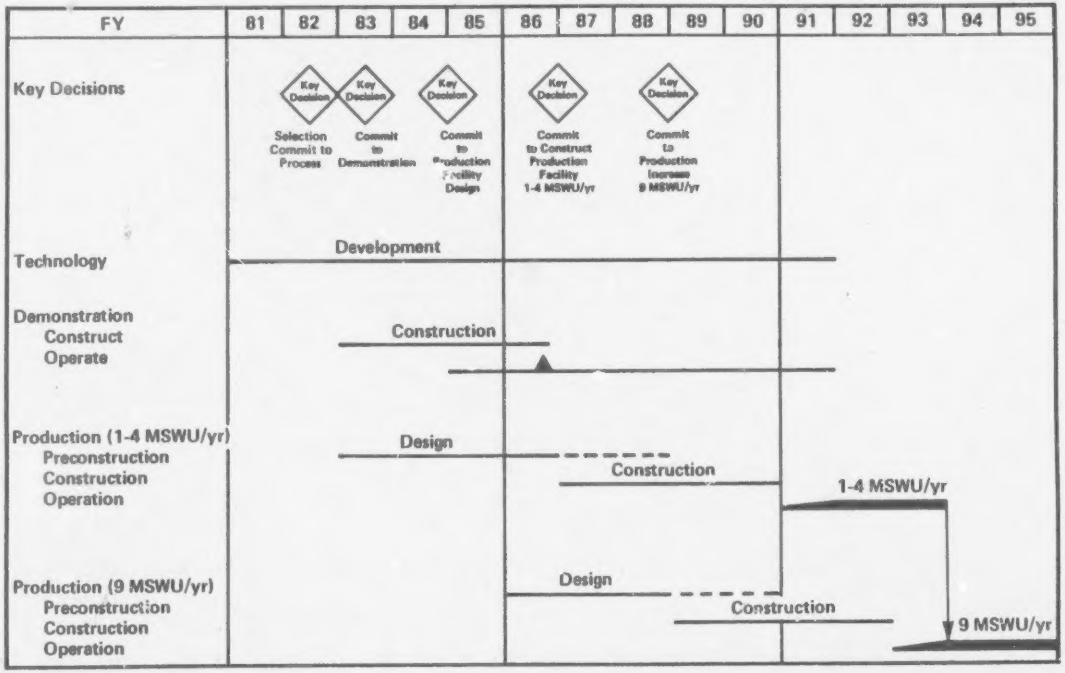
AVLIS SCHEDULE AND KEY DECISIONS



AIS BUDGET FOR PROPOSED PROGRAM (FY83$M)

FY	83	84	85	86	87	88	89	90	91	92	Total
Demonstration:											
AIS Core Technology	32	42	37	37	20	14	8	4	2		196
SIS* Laser Tech. Support	(14)	(23)	(17)	(10)	(4)						(68)
Systems: AIS	9	23	21	22	10	8	6	4	2		105
SIS* Support	(15)	(27)	(17)	(7)							(66)
Sub Total	41 (29)	65 (50)	58 (34)	59 (17)	30 (4)	22	14	8	4		301 (134)
Technology Improvement:											
AIS Technology			7	20	45	49	44	34	27	15	241
SIS* Laser Tech. Support			(11)	(15)							(26)
Sub Total			7 (11)	20 (15)	45	49	44	34	27	15	241 (26)
Production:											
Preconstruction Design			12	26							38
Construction					100	190	190	130			610
Sub Total			12	26	100	190	190	130			648
Total	41 (29)	65 (50)	77 (45)	105 (32)	175 (4)	261	248	172	31	15	1190 (160)

* Portion of SIS budget relevant to AIS Program.

AIS BUDGET THROUGH 1986/1987 DEMONSTRATION (FY83$M)

	FY83		FY84		FY85		FY86		Total	
	AIS	SIS *	AIS	SIS *	AIS	SIS *	AIS	SIS *	AIS	SIS *
Demonstration:										
AIS Core Technology	30.3		39.1		31.0		32.2		132.6	
SIS Laser Tech. Support		14.0		19.0		17.0		10.0		60.0
Systems Construction										
SISL Buildings		7.2								7.2
Laser Systems		7.3		25.2	5.7	10.7	8.2	3.0	13.9	46.2
Separator Systems	8.7		17.8		4.8		0.4		31.7	
Maintenance Equipment	0.5	0.5	2.5	1.2	1.4	0.9	0.4	0.4	4.8	3.0
Operation			2.9	1.0	9.0	5.0	12.6	4.0	24.5	10.0
Reserve	1.0		3.0		6.0		5.0		15.0	
Sub Total	40.5	29.0	65.3	46.4	57.9	33.6	58.8	17.4	222.5	126.4
Technology Improvement:										
AIS Technology					6.8		16.9		23.7	
SIS Laser Tech. Support				4.4		11.0		15.0		30.4
Reserve					0.9		2.6		3.5	
Sub Total				4.4	7.7	11.0	19.5	15.0	27.2	30.4
Production:										
Preconstruction Design					12.0		26.0		38.0	
Construction										
Sub Total					12.0		26.0		38.0	
Total	40.5	29.0	65.3	50.8	77.6	44.6	104.3	32.4	287.7	156.8

* Portion of SIS budget relevant to AIS Program.

THE CRITICS VIEW

- Cannot meet schedule
- Cannot meet costs
- Does not have value
- Cannot afford to fund it
- Program projections not credible
- Not ready

IMPLEMENTATION SCHEDULE

CRITICS VIEW:

AVLIS process cannot be implemented in a timely fashion. The proposed schedule is not practical.

RESPONSE:

AVLIS can be implemented in early 1990s. Comparisons based upon GCEP experience are not valid.

AVLIS PLANT CAN BE MORE RAPIDLY IMPLEMENTED THAN GDP AND GCEP

• Lower capital cost (0.1-0.2 GC) – Reduced scale is easier to build – Lower annual expenditures are easier to fund	⇨ Short construction time
• Industrial base does not need to be developed (no machine manufacturers) – Basic fabrication facilities are included in AVLIS plant	⇨ Short hardware procurement time
• Shorter component lifetime requirements (0.1-0.01 GC) – Shorter lifetimes are easier to attain – Life testing can be quickly done – Basic designs can be rapidly iterated	⇨ Short development time
• Critical parts are replaced often (10-100× GC) – Performance can be rapidly improved – Upgrades can be achieved rapidly at low cost	⇨ Plant production rate can be rapidly achieved

PROGRAM COSTS

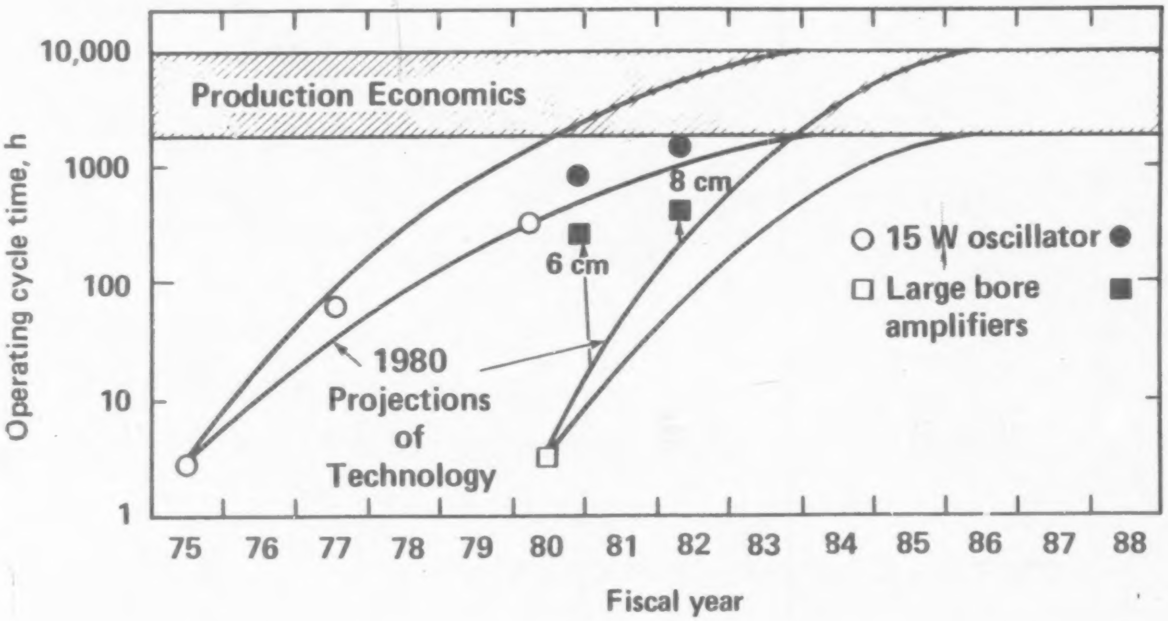
CRITICS VIEW:

AVLIS projects low costs but costs will grow as has happened with all previous enrichment processes.

RESPONSE:

AVLIS process is based on a new rapidly developing technology. Continued development will result in cost reductions, not growth.

LASER DEVELOPMENT HAS PROCEEDED MORE RAPIDLY THAN EXPECTED



SUMMARY OF AVLIS PROGRAM PROJECTIONS: EARLY ESTIMATES SUBSTANTIATED OR IMPROVED

	Previous Estimates* 1975-1981	Current Estimates 1983
Production cost	$10-40/SWU**	$21/SWU
Implementation time (Selection to deployment)	9-15 years	9 years
RD&D costs	$570M-$830M	$542M ($160M)
Plant capital cost (9 MSWU/y)	$800M-$1000M	$1050M

* FY83 dollars
**Initially in FY76 dollars

VALUE OF AVLIS

CRITICS VIEW:

We do not need AVLIS, we have GCEP and AGC. With a strong GC program we can capture and maintain the market.

RESPONSE:

- AVLIS is a superior process. It will provide lower cost SWUs and can be rapidly implemented.
- Successful implementation of AVLIS by a foreign competitor would seriously undermine U.S. enrichment enterprise.

PROGRAM FUNDING

CRITICS VIEW:

AVLIS is a drain on the available revenues and slows down GCEP implementation. SIS will fund AVLIS anyway. Wait until the process is fully developed.

RESPONSE:

AVLIS funding requirements are small; the benefit to the U.S. enrichment enterprise is large.

AIS lasers require a full generation of development beyond SIS lasers to achieve economic objective.

SIS separator involves totally different technology and does not support AIS separator technology.

CREDIBILITY OF AVLIS PROJECTIONS

CRITICS VIEW:

Program projections are not credible. AVLIS has been oversold.

RESPONSE:

AVLIS has a history of meeting its cost, schedule and performance projections.

- Cost estimates have been stable since 1976.
- Schedule estimates have been stable since 1976.
- Key milestones have been met since 1976.

ORIGINAL PROJECTIONS CONSISTENT WITH CURRENT STATUS

- Estimated development cost and schedule ranges have not changed.
- Results have validated our performance projections.
- Hardware development has proceeded more rapidly than projected.

SUMMARY OF AVLIS PROGRAM PROJECTIONS: EARLY ESTIMATES SUBSTANTIATED OR IMPROVED

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* FY83 dollars
**Initially in FY76 dollars

READINESS

CRITICS VIEW:

AVLIS is not ready for implementation.

RESPONSE:

AVLIS can demonstrate full scale performance in 1986/1987.

With this demonstration AVLIS can be rapidly implemented.

JOINT CONCLUSIONS AND RECOMMENDATIONS

It is the carefully considered opinion of both UCC-ND and LLNL that:

- The AVLIS process has the best potential for achieving low cost SWUs in the early 1990s.
- 1986/1987 Demonstration and 1991/1992 Production are achievable in both a management and technical sense.
- DOE commitment to the AVLIS program is important in view of the market situation.
- The AVLIS program should be funded at the highest priority in UEA.

JOINT RECOMMENDATION ON FUNDING PRIORITY

After minimum production requirements have been met, our joint recommendation for priority funding in uranium enrichment is:

1. Advanced technology demonstration
    a. AVLIS
    b. AGC
2. GCEP construction
3. Other

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Dr. **Merriman**. The basis for proposing the accelerated demonstration of AVLIS is, No. 1, the continued outlook for good potential of that technology.

No. 2, the demonstration of technical resolution of the thermal control issue during the past year.

No. 3, the SIS program, which allowed a path for demonstration some 3 years earlier than we had in our previous plan.

Those were the three factors.

Mr. **Winn**. Do those 3 years take into consideration an 1986-87 schedule?

Dr. **Merriman**. I am saying in the old plan the equivalent technical demonstration of AVLIS and the equivalent economic verification of AVLIS would have occurred in approximately the 1990 timeframe, and by being able to use the facilities—laser and labortory facilities at Livermore from the SIS program—we think that can be achieved some 3 years earlier.

Mr. **Winn**. There have been some rumors around that Union Carbide wants to get out of some of these contracts. You might want to give us that during the classified presentation. [Laughter.]

Dr. **Merriman**. I am not an officer of the company. I have no information other than what I have read—it is true Union Carbide has announced they, are not seeking to renew the contract at DOE for the Oak Ridge, Tenn., and Paducah, Ky., facilities.

Mrs. **Bouquard**. Thank you very much, gentlemen.

The subcommittee now is prepared to consider proceeding in executive session to receive testimony on the classified part of the uranium enrichment program.

Will the clerk call the roll, please?

The **Clerk**. Mrs. Bouquard?

Mrs. **Bouquard**. Aye.

The **Clerk**. Mr. Walker?

[No response.]

The **Clerk**. Mr. Roe?

[No response.]

The **Clerk**. Mr. Chandler?

[No response.]

The **Clerk**. Mr. Lundine?

[No response.]

The **Clerk**. Mr. Lujan?

[No response.]

The **Clerk**. Mr. Ottinger?

Mr. **Ottinger**. Aye.

The **Clerk**. Mr. Lowery?

[No response.]

The **Clerk**. Mr. Hall?

[No response.]

The Clerk. Mr. Valentine?

[No response.]

The **Clerk**. Mr. Fuqua?

[No response.]

The **Clerk**. Mr. Winn?

Mr. **Winn**. Aye.

Mrs. **Bouquard**. The clerk will report.

The **Clerk**. Three ayes.

Mrs. **Bouquard.** Accordingly, then, the subcommittee will proceed in executive session. It is my understanding the room has to be cleared and checked for security reasons.

We will stay in recess for about 20 to 30 minutes. As soon as it is cleared, we will come back in to executive session.

[Whereupon, at 3:05 p.m., the subcommittee recessed, to reconvene later the same day in executive session.]

APPENDIX

Department of Energy
Washington, D.C. 20585

May 6, 1983

Honorable Marilyn Lloyd
Chairman
Subcommittee on Energy Research
  and Production
Committee on Science and Technology
House of Representatives
Washington, D.C. 20515

Dear Ms. Lloyd:

On March 10, 1983, Deputy Assistant Secretary William R. Voigt, Jr., appeared before the Science and Technology Subcommittee on Energy Research and Production to discuss the authorization for uranium enrichment activities.

Following that hearing, you submitted written questions for responses to supplement the record. Enclosed are the answers to those questions. Please note that we have enclosed three questions for restricted use. They contain unclassified nuclear technology and should not be printed in the hearing record.

If you have any questions, please call Diana Diamond or Tom Pretorius of my staff on 252-4277. They will be happy to assist you.

Sincerely,
Thomas H. Pretorius
for Robert G. Rabben
Assistant General Counsel
for Legislation

Enclosure

Question 1: What are the components of DOE's uranium enrichment services pricing structure and what is the percentage of the price for each such component? Explain the basis for each component.

Answer 1: The major components and their percentage of the current price are:

Power	48%
Other Operating	12%
Depreciation	6%
Interest	25%
All Other	9%

The basis for including each of these components in the price is the uranium enrichment Criteria.

Question 2: Why is impute. interest related to the investment in the Gas Centrifuge Enrichment Plant (GCEP) included in the price of enrichment services considering that the plant is funded out of current revenues? Please identify any other imputed interest charges that are included in the price of services and explain why they are included if the expenditures for the program are at the level of revenues.

Answer 2: Interest is imputed on the investment in GCEP because the uranium enrichment Criteria requires DOE to impute interest on all enrichment related plant and equipment. Imputed interest is, therefore, recovered in the price of enrichment services. However, because it is an imputed cost and not a direct cost, it is not included in the uranium enrichment annual budget request. This phenomenon often causes confusion regarding the enrichment budget request because revenues are used to offset appropriation requests in any given year. To explain this situation, a discussion of the budget system and the accounting and pricing system is necessary.

The uranium enrichment budget consists of an annual request for BA, the authority to obligate and commit funds, to operate the enrichment complex, and to construct GCEP. The total cash collections or revenues are used to offset the requested budget authority. The uranium enrichment budget, similar to other budgets, does not contain requests for financing costs (imputed interest), depreciation and some other small "non-fund" costs.

The accounting and pricing systems used for enrichment services is different from the budget process. These systems recognize costs using standard accounting methods and includes all costs, budget and non-budget. The recognition of capital costs is a major difference. The budget process recognizes this item as obligations

Question 2: (continued)

are required (BA) or as the expenditures are made (budget outlays or BO). Accounting recognizes capital costs through depreciation expenses. When an accounting cost is recognized, i.e., depreciation and imputed interest, this cost is included in the price and produces revenues which recover the cost.

An example may help clarify the difference between the budget and accounting systems including the imputing of interest. Assume an uranium enrichment capital project will cost $80 million with the following budget request and depreciation schedules.

(Millions of Dollars)

Year	Budget Request in BA	Construction BO	Original Investment	Depreciation	Net Investment
1	50	20	20	0	20
2	30	40	60	0	60
3		20	80	10	70
4			80	10	60
5			80	10	50
6			80	10	40
7			80	10	30
8			80	10	20
9			80	10	10
10			80	10	0
Total	80	80			

The request for BA would be $50 million in year 1 and $30 million in year 2. The second column is the actual expenditure of funds, also known as BO. For construction projects, the actual expenditure of funds usually follows the commitment of funds. These first two columns are used in the budget process, they are not used directly in the accounting and pricing systems other than to determine the total investment. The third column simply sums the cumulative investment or expenditure of funds. The accounting and pricing

Question 2: (continued)

systems will recover the $80 million investment through annual depreciation expenses. In this example, an 8 year depreciation schedule was assumed resulting in a $10 million depreciation expense in years 3 through 10. Net investment (unrecovered expenditures) is the original investment (cash expenditures) less accumulated depreciation (recovered costs). The Criteria requires that interest be imputed on the unrecovered government investment. In this example, interest is imputed on the net investment column. Assuming a 10 percent interest rate, the following interest charges result.

(Millions of Dollars)

Year	Net Investment	Imputed Interest
1	20	2
2	60	6
3	70	7
4	60	6
5	50	5
6	40	4
7	30	3
8	20	2
9	10	1
10	0	0

In developing the charge for enrichment services, the $80 million and associated interest is recovered as follows:

(Millions of Dollars)

Year	Depreciation	Interest	Total
1	0	2	2
2	0	6	6
3	10	7	17
4	10	6	16
5	10	5	15
6	10	4	14
7	10	3	13
8	10	2	12
9	10	1	11
10	10	0	10
Total	80	36	116

(Answer 2: continued)

Therefore, the $80 million project is included in the budget only in year 1 and 2. The $80 million is recovered in the charge in years 3 through 10. Interest on the investment is included in years 1 through 9. The actual budget and pricing for GCEP is consistent with this example.

What is confusing is the situation that the total amount of revenues in a given year is currently equal to the total budget request, including capital projects. This situation does not automatically happen simply because of cost recovery pricing. For the last several years, the program has been able to equate the budget request with the revenue streams because the revenues incoming from depreciation and imputed interest together with the sale of preproduced inventory have been sufficient to cover the budget requests needed for GCEP. This will not necessarily occur every fiscal year.

Imputed interest charges are included on all government investment in uranium enrichment including GCEP, other plant and equipment, separative work and natural uranium inventories needed to provide enrichment services, and working capital.

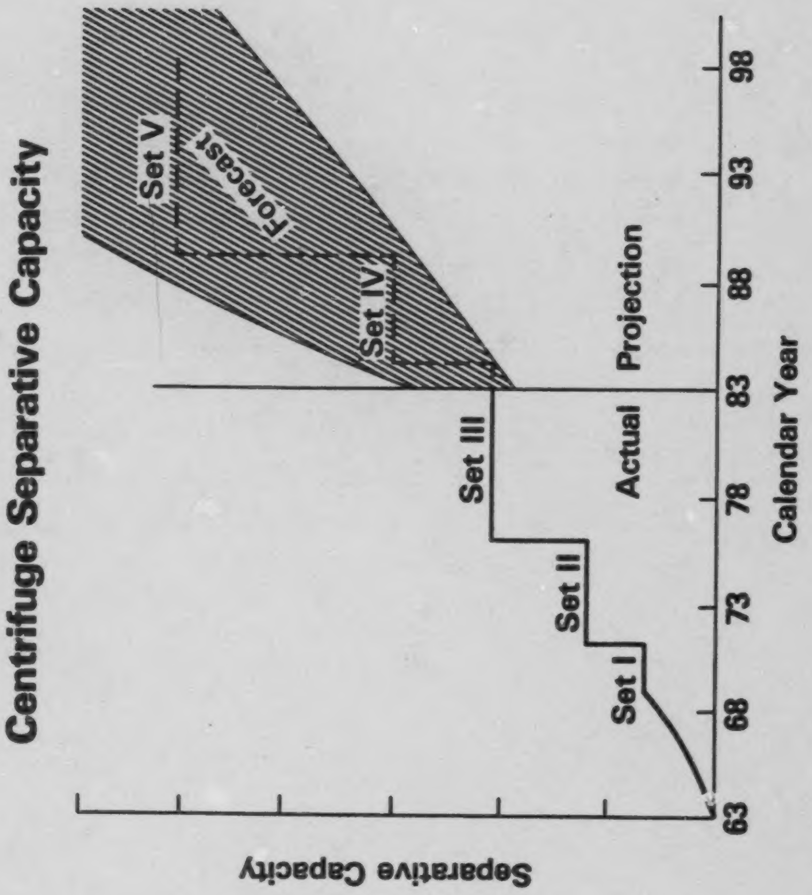
Question 3: What measures, such as revenue carryover, would be of most benefit to DOE's management of the uranium enrichment enterprise?

Answer 3: The near-term surplus separative work sales and revenues are fairly uncertain from year-to-year. The revenue uncertainties make planning and execution of this multi-billion dollar program very difficult.

The authority to carryover any excess revenues from 1 year to another could be helpful, however, over the next 5-10 years, no significant amount of excess revenues are expected to be generated.

Question 4:	If the total GCEP capacity exceeds projected SWU requirements, then all U.S. enrichment capacity could conceivably be located at one site, namely Portsmouth. What would be the Department's views on such a situation?
Answer 4:	The current capacity of GCEP is 13.2 million SWU beginning in 1994. The projected requirement for SWU in the mid-1990's is almost twice the GCEP capacity. Therefore, the current GCEP deployment strategy does not present a problem. When, and if, a technology is developed that has the potential of producing enrichment services at one location that exceeds the demand for enrichment services, we would assess the benefits of the low cost of production versus the risks of a single location operation.

Answer 4: (continued)



Question 5: Do the centrifuge manufacturers guarantee the separative work performance of each machine they manufacture under the terms of the current Phase I contracts? If not, why?

Answer 5: The centrifuge manufacturers (CMs) do not guarantee the separative work performance of any centrifuge machines. The CMs fabricate the machine components to detailed Government drawings and specifications. Since the manufacturers do not assemble those machines, they do not have control over the final manufacturing process, and therefore, the final machine performance. In Phase I, the CMs have manufactured Set III machine components that have been assembled, tested and qualified by other contractors. The latest and most extensive in this continuing series of qualification tests of Phase I centrifuges is operation of the Centrifuge Plant Demonstration Facility (CPDF). In CPDF, the Set III machines have shown a slightly higher SWU performance than CMs baseline design and about 50 percent better reliability. At GCEP, the DOE contractor operating the Recycle/Assembly Building will assemble all gas centrifuge machines from manufacturers' components before installation in the Process Buildings.

Question 6: At the top of page 6 of your testimony you state: "Three U.S. utilities and three foreign companies replaced approximately $30 million of potential U.S. sales during 1982 with heavily discounted excess foreign origin enrichment material." Please identify these three U.S. utilities and three foreign companies. How much did each of the three U.S. utilities save their rate payers by these actions?

Answer 6: The three U.S. utilities are Commonwealth Edison, Florida Power and Light, and Wisconsin Public Service Corporation. The three foreign companies are Sydkraft in Sweden, ENUSA in Spain, and the Taiwan Power Company in Taiwan. DOE does not have cost figures on how much the U.S. utilities saved as a result of purchasing discounted separative work.

Question 7: What is the likelihood that near-term revenue shortfalls will necessitate the slowdown of the construction of the Gas Centrifuge Enrichment Plant (GCEP), and how does DOE intend to respond?

Answer 7: In FY 1983, 1984 and probably 1985, revenues appear to be adequate to meet the budget requirements to operate the existing enrichment plants, maintain the current GCEP schedule, and conduct research into advanced centrifuge and laser technologies. In the outyears, the revenue situation is less optimistic. The Department is currently assessing the revenue situation and the entire range of strategies available to the enrichment program as an intregal part of preparing the FY 1985 budget request. It is too early to predict what, if any, changes will be needed to the enrichment program including any revisions to the GCEP schedule.

Question 8: The promise of the Set V Advanced Gas Centrifuge suggests that work on the Gas Centrifuge Enrichment Plant GCEP) could be delayed until these machines are designed, developed and demonstrated. Is this practical, and if not, why?

Answer 8: It is not practical or economical to delay work on the GCEP. Design is nearly complete, construction and U.S. industry are mobilized. The project is on schedule and within budget. Therefore, both the technical and economic success of this project seem reasonably assured in the near term. The advanced gas centrifuge designs we are pursuing are projected to produce GCEP compatible machines comparable in economics to any other advanced technology.

The additional cost of a delay of four and one half years while Set V centrifuges are developed and qualified for production would be as follows:

Project capital cost:	$1.25 billion in FY 1984 dollars
Interest on construction:	$1.7 billion in FY 1984 dollars
Operating costs:	$90 million in FY 1984 dollars
Differential cost of diffusion plant production over centrifuge production:	$3.6 billion in FY 1984 dollars

The high cost of enrichment from the existing gaseous diffusion plants has already contributed to the loss of 65 percent of the foreign market and is seriously threatening our domestic market. This market under our current contracts is valued at $100 billion between now and the end of the century.

Question 9: If the full eight-building Gas Centrifuge Enrichment Plant (GCEP) were completed on schedule, and if Set III centrifuges were deployed in Buildings 1 and 2, and Set IV machines in the remaining six buildings, how would the U.S. Separative Work Unit (SWU) prices in the late 1990's compare with the expected competition prices?

Answer 9: The above description of deploying centrifuge machines in GCEP is the deployment schedule contained in the current DOE long-term operating plan for the enrichment complex. We have projected our selling prices under this plan and our competitor's prices and beginning in the early 1990's the DOE price should be below the competitors price. By the mid to late 1990's, DOE would enjoy a significant price advantage.

Question 10: If only two buildings of the Gas Centrifuge Enrichment Plant (GCEP) were completed and the development of the Atomic Vapor Laser Isotope Separation (AVLIS) process proved unsuccessful, how would the U.S. Separative Work Unit (SWU) prices in the late 1990's compare with the expected competition prices?

Answer 10: In this technology deployment schedule, the projected DOE selling price is significantly higher than the projected prices for the full eight building, Set IV, GCEP. However, perhaps by the late 1990's or the turn of the century depending on inflation rates and foreign exchange rates, this deployment schedule should yield a selling price below our competitors price.

Question 11: *RESTRICTED USE* Answers in Committee files.

Question 12: *RESTRICTED USE* Answers in Committee files.

Question 13: What mechanisms are in place for sharing detailed technology, plans, costs, etc., relative to the Atomic Vapor Laser Isotope Separation (AVLIS) process with the private sector firms now involved in uranium enrichment?

Answer 13: The Department of Energy is currently evaluating existing and proposed mechanisms to find the appropriate means of sharing AVLIS technology with private sector firms consistent with Departmental classification and non-proliferation policies. Options include an extension of the Industrial Participation Program which has been in place for several years or modifications of existing contracts with private industry firms now involved in uranium enrichment. The Industrial Participation Program allows technology to be made available to qualified industrial organizations in order to establish a commercial infrastructure to support the Government's large-scale inplementation of the technology.

In addition, we will consider the procurement of selected components or subsystems from private industrial firms which are not now involved in uranium enrichment.

Question 14: What are the estimated remaining development costs for the Atomic Vapor Laser Isotope Separation (AVLIS) process?

Answer 14: The total estimated remaining development costs for the AVLIS process are approximately $550 million in FY 1984 dollars. If the AVLIS Program successfully meets its milestones, DOE will have sufficient information by the end of FY 1987 to decide on whether or not to commit this technology to production.

Question 15: Please identify the unit cost of production from GCEP for the three cases of Sets III, IV, and V machines in 2 and 8 buildings, respectively, at Portsmouth.

Answer 15: The requested data are as follows:

GCEP Unit Production Costs
(FY 1984 dollars per SWU)

Set III		Set IV		Set V	
2 Bldg.	8 Bldg.	2 Bldg.	8 Bldg.	2 Bldg.	8 Bldg.
258	116	172	77	93	41

Question 16: Please compare in tabular form the full and incremental costs (in $/SWU) of GCEP (Set III, IV, and V) and AVLIS technologies, identifying both capital and operating components.

Answer 16: The requested data are as follows:

Unit Costs
(FY 1984 dollars per SWU)

	Set III		Set IV		Set V		AVLIS
	2 Bldg.	8 Bldg.	2 Bldg.	8 Bldg.	2 Bldg.	8 Bldg.	
Full Cost							
Capital	199	87	133	58	73	32	9
Operating	59	29	39	19	20	9	22
Total	258	116	172	77	93	41	31
Incremental Cost							
Capital	108	63	72	42	40	24	9
Operating	59	29	39	19	20	9	22
Total	167	92	111	61	60	33	31

When comparing these costs, several factors should be noted:

1. Current decisionmaking should be based on the incremental cost rather than full cost. The costs to date are sunk costs. What is important in current decisionmaking are the costs to complete and to operate the plant.

2. The costs presented in the table do not include contingencies related to technological risk and, therefore, do not reflect the same level of confidence. The bases for cost estimates vary substantially. The Set III GCEP estimates are based on a technology that is routinely demonstrating production of marketable product and on plant construction where over 60 percent of the cost is historical or reflects fixed

Question 16: (continued)

price bid experience. On the other hand, AVLIS has only demonstrated technical feasibility in physics experiments (not fully integrated) and plant cost is based on limited preconceptual design. Set IV GCEP is an extrapolation of current technology and is, therefore, less certain than Set III GCEP. Set V GCEP is a further extrapolation of current technology resulting in substantially larger uncertainty than Set IV.

Question 17: If the Atomic Vapor Laser Isotope Separation (AVLIS) process proves successful and were operating on tails stripping only beginning in 1992, how much of the expected enrichment demand could it supply?

Answer 17: If the current Livermore proposal proves to be successful, up to 4 million separative work units (SWU) of AVLIS capacity could be available by FY 1992. This capacity can be used to either meet the demand for enrichment services to provide reactor grade uranium or to strip tails. To the extent that this capacity is used to strip tails, it is not available to meet demand.

Tails stripping usually refers to the use of existing uranium stocks depleted in the U-235 isotope as feed for the enrichment plant. This mode of operation results in a reduced natural uranium demand but requires additional SWU to increase the U-235 content of the feed to 0.711 percent (i.e., percent U-235 in natural uranium). Currently, we have no firm plans to do tails stripping.

Question 18: Is DOE planning to initiate a detailed design of the Oak Ridge phased production facility for AVLIS?

Answer 18: DOE received a joint proposal from Lawrence Livermore National Laboratory (LLNL) and Union Carbide Corporation - Nuclear Division (UCC-ND) that presents the opportunity for early demonstration and deployment of AVLIS. One of the key features of this proposal is a thorough engineering design of a full-scale production plant. A conceptual design will be initiated in FY 1984. The timing for the initiation of the detailed design of the facility is currently under evaluation.

Question 19: What steps are being taken to insure timely deployment of Advanced Gas Centrifuges (AGC's) in GCEP?

Answer 19: The Department of Energy is carefully reviewing possible options for accelerating the performance evaluations of the Set IV and Set V gas centrifuge designs, to assure earliest possible availability for deployment in GCEP. The normal progression of development is to assess hardware features and performance changes, incorporate the most effective combination into a test vehicle, evaluate the separative performance of the full-scale gas centrifuge over a range of operating parameters, and finally, subject a large number of reliability machines to extending performance testing. Once reliability has been established, the production design would be fixed and orders placed for production model gas centrifuges. Our present assessment centers on determining the increased risk associated with overlapping certain of these steps. For example, if performance is satisfactory, is it feasible to proceed with manufacture of production centrifuges in parallel with the reliability testing? Such an approach would shorten the time for plant availability testing of a given centrifuge model, but introduces a risk by assuming that reliability testing will be satisfactory.

The evaluation of optimum development paths for the Set IV and Set V designs will be completed by the end of May 1983, including an assessment of the impacts of different availability schedules on the cost of separative work.

Question 20: What options are being considered for the deployment of combinations of Set III, Set IV, and Set V machines?

Answer 20: We are presently evaluating the technical and economic consequences of modifications to the present schedule for deployment of the baseline and advanced gas centrifuges. The options include: (a) acceleration of Set V deployment while maintaining Set IV deployment; (b) acceleration of Set V deployment while terminating Set IV deployment; (c) maintaining Set IV on the present schedule while terminating Set V development; and (d) early termination of both Set IV and Set V development, with sole reliance on the baseline, Set III, centrifuge for deployment in GCEP.

The above assessment is, of course, quite dependent on judgment, since the three centrifuge machines are at different stages of development. The Set III machine is fully qualified and demonstrated for use in GCEP and we have established that its reliability exceeds the plant requirement. The Set IV machine has attained 1.4 times the total separative performance of the Set III machine (the goal being a factor of 1.5 times improvement over the Set III Machine), but evaluation of specific design features is still in progress. We will be able to verify the success of the Set IV machine design through full-scale testing that is scheduled for completion in FY 1984. The Set V machine is in the earliest stage of

Question 20: (continued)

development. While it has the greatest promise of increased separative performance (a factor of 2 to 3 times better than Set III), a great deal of work must still be conducted to verify fabrication technology, verify operating characteristics, and determine reliability of performance. As a consequence of these different levels of understanding, the evaluation of the deployment options will require the best possible judgment in estimating gains to be realized from work not yet conducted.

Question 21: What is the first element of the Gas Centrifuge Enrichment Plant (GCEP) into which some Advanced Gas Centrifuge (AGC) components could be introduced, assuming unlimited funding?

Answer 21: Unlimited funding and complete research and development success could make AGC centrifuges available for initial installation in part of Process Building 2 and all of Process Buildings 3 through 8. However, the GCEP completion dates would slip about 2 years.

Question 22: What are the estimated remaining development costs for the Set V Advanced Gas Centrifuge (AGC)?

Answer 22: The present Set V program was initiated in January 1983. The overall development cost (in FY 1984 dollars) is estimated to be $400 million, including reliability testing of the Set V design selected.

Question 23: Is the Department going to conduct a detailed socioeconomic study to determine community impacts of the closure of each of the GDP's and if so, what is the time schedule for the completion of these studies.

Answer 23: The current study on GDP shutdown, in addition to reviewing economic and technical issues, will also analyze the impact on the community caused by a site shutdown. A separate detailed socioeconomic study is not currently planned. The initial phase of the current study is expected to be completed in the next few months.

Question 24: Since all power contracts for the GDP's expire in the early 1990's, is DOE considering the purchase of CRBR power as an element of firm contract demand power in the 1990's and beyond?

Answer 24: At this time DOE does not have any current plans to purchase CRBR power in the 1990's. The long range plan for uranium enrichment anticipates the shutdown of one of the gaseous diffusion plants by the early 1990's. In addition, development of the advanced gas centrifuge technology and the atomic vapor laser isotope separation process is underway. These two technologies will be available by the early 1990's and will allow DOE to choose a technology for possible replacement of additional capacity in the higher production cost gaseous diffusion plants.

In view of this, it is not reasonable to expect the uranium enrichment program to commit to purchase on a firm basis the output of the CRBR.

Question 25: Have there been any productivity break-throughs in the gas centrifuge enrichment program since construction began?

Answer 25: It is assumed this question pertains to the separative performance of gas centrifuge designs. The Set III baseline gas centrifuge, planned for installation in the first two buildings of the Gas Centrifuge Enrichment Plant (GCEP), has met or exceeded all design expectations. Individual centrifuges have consistently produced separative work at the desired annual rate, and Set III centrifuges in cascade configuration have also performed more reliably than expected.

The Set IV machines have demonstrated the ability to perform at 1.4 times the separative capacity of the Set III machine (the goal being a factor of 1.5 times improvement over the baseline Set III Machine). On-going work is expected to help attain the full improvement that is desired.

Set V is in the very early stages of development, and we are presently assessing optimum techniques for fabrication of rotors using improved construction materials. Testing of full-scale rotors will begin late this year and extend through FY 1984. Whether the Set V concept will achieve the desired factor of 2 to 3 times increase in separative performance over Set III must still be verified by full-scale testing.

Question 26: What is the earliest time that the Atomic Vapor Laser Isotope Separation (AVLIS) process could be brought on line?

Answer 26: The accelerated program plan for demonstration and early deployment of AVLIS shows that the AVLIS process could be brought on line in the early 1990's. The plan proposes construction of a phased production plant with 4 million SWU capacity in 1992 and concluding in 1994 with a total production capacity of 9 million SWU.

Question 27: What would be the costs of this alternative?

Answer 27: At present, we cannot give definitive costs of this alternative. Current estimates to construct a 9 million SWU plant is roughly $1.0 billion in FY 1984 dollars. Prior to operation, about $550 million is required for development costs and about $220 million is required for conversion facilities. These cost estimates will be continually scrutinized and updated in the course of the development program.

Question 28: What would happen to our international market for enriched uranium if the United States waited for this new technology? What would be the actual cost in dollars and cents?

Answer 28: If the United States halted both centrifuge development and GCEP construction while waiting for successful development and commercial operation of the Atomic Vapor Laser Isotope Separation (AVLIS) process, the ability of the United States to compete in both the domestic and international market would be questionable during this waiting period. Waiting for the AVLIS process means that the Department would have to rely on the costly production from the diffusion plants for an extended period. The result will be higher selling prices and a loss of sales in today's highly price competitive market.

Question 29: Would such a delay place at risk the entire self-supporting enrichment program at a cost of millions of dollars?

Answer 29: Waiting for the AVLIS process means that the Department would have to rely on the costly production from the diffusion plants for an extended period. The result will be higher selling prices and a loss of sales in today's highly price competitive market. This loss of revenues could extend through the mid to late 1980's and will probably result in revenues being insufficient to meet the total budget requirements. To the extent that appropriations would not be forthcoming, it may not be possible to continue the research on attractive technologies and/or the rapid deployment of the technologies. Unfortunately, this in turn could cause the loss of further revenues.

Question 30: What is the outlook for enrichment revenues for the next 5 to 10 years and how do these match up with expected outlays?

Answer 30: As was mentioned earlier, the revenue situation in the post FY 1985 period is very difficult to predict. Actual sales and revenue projections for this period are contingent on the level of activity of the secondary market and on inroads into our markets by our primary competitors. The Department is currently assessing the revenue situation and is examining the entire range of technology deployment options to determine how the budget requirements for each option compares to expected revenues. The analysis will also consider the economic impact of each option and the resulting selling prices. This effort is an integral part of the FY 1985 budget preparation process.

Question 31: How vulnerable is the United States' enrichment enterprise to secondary market and other competitive pressures?

Answer 31: Secondary market and other competitive pressures could present a serious challenge to the United States enrichment enterprise. DOE must continue to increase process efficiencies and maintain competitive SWU prices through deployment of new and improved technologies.

Question 32: What are the current prices of Separative Work Units on the secondary market, and from EURODIF and URENCO?

Answer 32: Currently, separative work unit (SWU) prices on the secondary market are in the range of $95 per SWU to $115 per SWU. The current EURODIF price to equity partners is reported to be 925 French francs per SWU, which at the mid-April 1983 exchange rate of 7.25 French francs per dollar is approximately $128 per SWU. The current URENCO price is reported to be about $130 per SWU.

Question 33: What is the Department's response to the proposal submitted by Lawrence Livermore National Laboratory and Union Carbide Corporation to accelerate the pace of the AVLIS Program?

Answer 33: The Department has accepted the R&D strategy proposed by Lawrence Livermore National Laboratory (LLNL) and Union Carbide Corporation - Nuclear Division and has directed them to proceed with the early large-scale process demonstration at LLNL. We have, however, reserved judgment on the need for line item funding in FY 1985 for the phased production facility.

Question 34: When will DOE initiate the detailed design of the Oak Ridge phased production facility?

Answer 34: Conceptual design activities initiated in FY 1984 will be continued and refined in FY 1985 and will be used to bound the plant capital cost. The timing for the initiation of the detailed design of this facility is currently under evaluation.

Question 35: *RESTRICTED USE* Answers in Committee files.

Question 36: What are DOE's current plans with regard to the possible shutdown of the gaseous diffusion plants (GDP's)?

Answer 36: DOE's long range operating plan analysis indicates that shutdown and replacement of expensive gaseous diffusion capacity will be required in the early 1990's. It is necessary to shutdown expensive capacity and replace it with lower cost centrifuge or laser capacity to remain price competitive in the market.

Question 37: Since all power contracts for the GDP's expire in the early 1990's, will DOE negotiate with each supplier prior to a shutdown decision to obtain the "best and final" contracts for the remaining plant operations or will DOE use current contract terms as the primary cost input to the GDP shutdown decision?

Answer 37: As part of the GDP shutdown study, DOE will project the cost of power from each of the three suppliers. This projection will be based in part on data provided by the suppliers and on DOE's independent analysis of future power costs. For the shutdown study, the contractual terms will essentially be based on the current contracts with some changes coming about from discussions with the suppliers concerning power deliveries in the 1990's.

ADDITIONAL QUESTIONS FOR MR. VOIGT
HEARING ON URANIUM ENRICHMENT ACTIVITIES
March 10, 1983

- 1 What are the components of DOE's uranium enrichment services pricing structure and what is the percentage of the price for each such component? Explain the basis for each component.

- 2 Why is imputed interest related to the investment in the Gas Centrifuge Enrichment Plant (GCEP) included in the price of enrichment services considering that the plant is funded out of current revenues? Please identify any other imputed interest charges that are included in the price of services and explain why they are included if the expenditures for the program are at the level of revenues.

- 3 What measures, such as revenue carryover, would be of most benefit to DOE's management of the uranium enrichment enterprise?

- 4 If the total GCEP capacity exceeds projected SWU requirements, then all U.S. enrichment capacity could conceivably be located at one site, namely Portsmouth. What would be the Department's views on such a situation?

- 5 Do the centrifuge manufacturers guarantee the separative work performance of each machine they manufacture under the terms of the current Phase I contracts? If not, why?

- 6 At the top of page 6 of your testimony you state: "Three utilities and three foreign companies replaced approximately $30 million of potential U.S. sales during 1982 with heavily discounted excess foreign original enrichment material." Please identify these three U.S. utilities and three foreign companies. How much did each of the three U.S. utilities save their rate payers by these actions?

- 7 What is the likelihood that near-term revenue shortfalls will necessitate the slowdown of the construction of the Gas Centrifuge Enrichment Plant (GCEP), and how does DOE intend to respond?

- 8 The promise of the Set V Advanced Gas Centrifuge suggests that work on the Gas Centrifuge Enrichment Plant (GCEP) could be delayed until these machines are designed, developed and demonstrated. Is this practical, and if not, why?

- 9 If the full eight-building Gas Centrifuge Enrichment Plant (GCEP) were completed on schedule, and if Set III centrifuges were deployed in Buildings 1 and 2, and Set IV machines in the remaining six buildings, how would the U.S. Separative Work Unit (SWU) prices in the late 1990's compare with the expected competition prices?

- 10 If only two buildings of the Gas Centrifuge Enrichment Plant (GCEP) were completed and the development of the Atomic Vapor Laser Isotope Separation (AVLIS) process proved unsuccessful, how would the U.S. Separative Work Unit (SWU) prices in the late 1990's compare with the expected competition prices?

- 11 What do the existing Phase I and proposed Phase II contracts with the three centrifuge manufacturers require in the way of performance and price? Restricted

- 12 How much is each of the three centrifuge manufacturers receiving, on the average, per machine, under the current Phase I cost plus fixed fee (CPFF) contracts? Restricted

- 13 What mechanisms are in place for sharing detailed technology, plans, costs, etc. relative to the Atomic Vapor Laser Isotope Separation (AVLIS) process with the private sector firms now involved in uranium enrichment?

- 14 What are the estimated remaining development costs for the Atomic Vapor Laser Isotope Separation (AVLIS) process?

- 15 Please identify the unit cost of production from GCEP for the three cases of Sets III, IV, and V machines in 2 and 8 buildings, respectively, at Portsmouth.

- 16 Please compare in tabular form the full and incremental costs (in $/SWU) of GCEP (Set III, IV,and V) and AVLIS technologies, identifying both capital and operating components.

- 17 If the Atomic Vapor Laser Isotope Separation (AVLIS) process proves successful and were operating on tails stripping only beginning in 1992, how much of the expected enrichment demand could it supply?

- 18 Is DOE planning to initiate a detailed design of the Oak Ridge phased production facility for AVLIS?

- 19 What steps are being taken to insure timely deployment of Advanced Gas Centrifuges (AGC's) in GCEP?

- 20 What options are being considered for the deployment of combinations of Set III, Set IV, and Set V machines?

- 21 What is the first element of the Gas Centrifuge Enrichment Plant (GCEP) into which some Advanced Gas Centrifuge (AGC) components could be introduced, assuming unlimited funding?

- 22 What are the estimated remaining development costs for the Set V Advanced Gas Centrifuge (AGC)?

- 23 Is the Department going to conduct a detailed socioeconomic study to determine community impacts of the closure of each of the GDP's and if so, what is the time schedule for the completion of these studies?

- 24 Since all power contracts for the GDP's expire in the early 1990's, is DOE considering the purchase of CRBR power as an element of firm contract demand power in the 1990s and beyond?

ADDITIONAL QUESTIONS BY CONGRESSMAN McEWEN
HEARING ON URANIUM ENRICHMENT
March 10, 1983

- 25 Have there been any productivity break-throughs in the gas centrifuge enrichment program since construction began?
- 26 What is the earliest time that the atomic vapor laser isotope separation (AVLIS) process could be brought on line?
- 27 What would be the costs of this alternative?
- 28 What would happen to our international market for enriched uranium if the United States waited for this new technology? What would be the actual cost in dollars and cents?
- 29 Would such a delay place at risk the entire self-supporting enrichment program at a cost of millions of dollars?

General

- 30 What is the outlook for enrichment revenues for the next 5 to 10 years and how do these match up with expected outlays?
- 31 How vulnerable is the United States' enrichment enterprise to secondary market and other competitive pressures?
- 32 What are the current prices of Separative Work Units on the secondary market, and from EURODIF and URENCO?
- What is the likelihood that revenue problems will necessitate the slowdown of the construction of the Gas Centrifuge Enrichment Plant (GCEP), and how does DOE intend to respond? See Q 7
- What measures, such as revenue carryover, would be of most benefit to DOE's management of the uranium enrichment enterprise? See Q 3

AVLIS

- 33 What is the Department's response to the proposal submitted by Lawrence Livermore National Laboratory and Union Carbide Corporation to accelerate the pace of the AVLIS program?
- 34 When will DOE initiate the detailed design of the Oak Ridge phased production facility?

AGC

- What steps are being taken to insure timely deployment of Advanced Gas Centrifuges (AGCs) in GCEP? See Q19
- What options are being considered for the deployment of combinations of Set III, Set IV, and Set V machines? See Q20

- 35 What are the projected costs and projected SWU capabilities of Set III, Set IV and Set V machines? restricted use

- If the total GCEP capacity exceeds projected SWL requirements, then all U.S. enrichment capacity could conceivably be located at one site, namely Portsmouth. What would be the Department's views on such a happenstance? See Q 4

GDP

- 36 What are DOE's current plans with regard to the possible shutdown of the Gaseous Diffusion Plants (GDPs)?

- Is the Department going to conduct a detailed socioeconomic study to determine community impacts of the closure of each of the GDPs and if so, what is the time schedule for the completion of these studies? See Q23

- 37 Since all power contracts for the GDPs expire in the early 1990's, will DOE negotiate with each supplier prior to a shutdown decision to obtain the "best and final" contracts for the remaining plant operations or will DOE use current contract terms as the primary cost input to the GDP shutdown decision? See Q 24

BOB MCEWEN
6TH DISTRICT, OHIO

PUBLIC WORKS AND
TRANSPORTATION COMMITTEE

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SURFACE TRANSPORTATION
ECONOMIC DEVELOPMENT
INVESTIGATIONS AND OVERSIGHT

VETERANS' AFFAIRS

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HOUSING AND MEMORIAL AFFAIRS
HOSPITALS AND HEALTH CARE

AGRICULTURAL TASK FORCE
CHAIRMAN

Congress of the United States
HOUSE OF REPRESENTATIVES
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March 10, 1983

The Honorable Marilyn L. Bouquard
Chairman
Subcommittee on Energy Research
and Production
B374 Rayburn House Office Building
Washington, D.C. 20515

Dear Madame Chairman:

Thank you for the opportunity to participate in the subcommittee's hearing regarding uranium enrichment scheduled for this afternoon.

Enclosed please find a list of questions to be directed either to Mr. Voigt or Mr. Merriman. If you would be so kind as to include the questions and answers in the record of this hearing, I would be most grateful.

Again, Madame Chairman, I appreciate your courtesy in submitting these questions on my behalf.

With kindest regards,

Sincerely,

Bob McEwen
Member of Congress

BM:ly

1. Have there been any productivity break-throughs in the gas centrifuge enrichment program since construction began?
2. What is the earliest time that either the advanced isotope separation (AIS) or the atomic vapor laser isotope separation (AVLIS) process could be brought on line?
3. What would be the costs of these alternatives?
4. What would happen to our international market for enriched uranium if the United States waited for this new technology? What would be the actual cost in dollars and cents?
5. Would such a delay place at risk the entire self-supporting enrichment program at a cost of millions of dollars?

QUESTIONS FOR DOE ON URANIUM ENRICHMENT - March 10, 1983

General

1. What is the outlook for enrichment revenues for the next 5 to 10 years and how do these match up with expected outlays?

2. How vulnerable is the United States' enrichment enterprise to secondary market and other competitive pressures?

3. What are the current prices of Separative Work Units on the secondary market, and from EURODIF and URENCO?

4. What is the likehood that revenue problems will necessitate the slowdown of the construction of the Gas Centrifuge Enrichment Plant (GCEP), and how does DOE intend to respond?

5. What measures, such as revenue carryover, would be of most benefit to DOE's management of the uranium enrichment enterprise?

AVLIS

1. What is the Department's response to the proposal submitted by Lawrence Livermore National Laboratory and Union Carbide Corporation to accelerate the pace of the AVLIS program?

2. When will DOE initiate the detailed design of the Oak Ridge phased production facility?

AGC

1. What steps are being taken to insure timely deployment of Advanced Gas Centrifuges (AGC's) in GCEP?

2. What options are being considered for the deployment of combinations of Set III, Set IV, and Set V machines?

3. What are the projected costs and projected SWU capabilities of Set III, Set IV and Set V machines?

4. If the total GCEP capacity exceeds projected SWU requirements, then all U.S. enrichment capacity could conceivably be located at one site, namely Portsmouth. What would be the Department's views on such a happenstance?

GDP

1. What are DOE's current plans with regard to the possible shutdown of the Gaseous Diffusion Plants (GDP's)?

2. Is the Department going to conduct a detailed socioeconomic study to determine community impacts of the closure of each of the GDP's and if so, what is the time schedule for the completion of these studies?

3. Since all power contracts for the GDP's expire in the early 1990's, will DOE negotiate with each supplier prior to a shutdown decision to obtain the "best and final" contracts for the remaining plant operations or will DOE use current contract terms as the primary cost input to the GDP shutdown decision?

UNION
CARBIDE

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
P. O. BOX P, OAK RIDGE, TENNESSEE 37830

May 5, 1983

The Hon. Marilyn Lloyd
House of Representatives
Washington, D. C. 20515

Dear Ms. Lloyd:

Enclosed, as you requested, are my responses to the additional questions pertaining to the uranium enrichment program which you sent in your letter of March 24, 1983.

Very truly yours,

J. R. Merriman, Director
Enrichment Technology

JRM:cr

Enclosures: As stated

cc: File - JRM

Question 1. What are the differences between the Atomic Vapor Laser Isotope Separation (AVLIS) Development/Demonstration Module (DDM), the Special Isotope Separation Laboratory (SISL) Demonstration Facility, and the Phased Production Facility?

Response: These differences are outlined in the attached chart (Supplementary Chart 1). The Special Isotope Separation (SISL) facility will enable a technical demonstration of AVLIS that is essentially equivalent to that previously planned for the Development/Demonstration Module (DDM). This demonstration will establish process performance and economics at essentially full-scale plant conditions. Because of the support from the Special Isotope Separation Program, however, the SISL demonstration can occur in the 1986/1987 time frame as opposed to 1990/1991 for the DDM, and the total demonstration program can be completed not only earlier, but also for some $250 million less. Successful demonstration in SISL will enable a more rapid deployment of an AVLIS production plant. The previous plan called for an AVLIS plant in 1995, but the new plan has the goal of startup of a phased production facility (PPF) in Oak Ridge in 1991.

Question 2. If the proposed Atomic Vapor Laser Isotope Separation (AVLIS) demonstration is successful, how well will you be able to project the Separative Work Unit (SWU) cost of the AVLIS process?

Response: The goal of the AVLIS program is to achieve a production plant SWU cost in the $20-40/SWU range in the early 1990s. The goals of the 1986/1987 demonstration are to:

- Validate in integral systems at full plant scale and under plant operating conditions the key process technical performance parameters, such as
  - SWU/kgU, and
  - SWU/joule
- Bound capital costs through actual demonstration system component and subsystem costs which are within a factor of three of the plant projections.
- Have a detailed engineering design of the production facility to adequately support the cost projections.
- Bound operating costs by demonstrating key operating and maintenance cycle times and materials and requirements.

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DWG. NO. K/G-83-764

NEW AVLIS PROGRAM PLAN ACCELERATES PRODUCTION DEPLOYMENT

	OLD PLAN	NEW PLAN
DEMONSTRATION FACILITY	Production Prototypical Hardware — 4 Units	Production Prototypical Hardware — 1 Unit
• Operational Date	1990	1986
• Construction	New 100,000 Sq. ft. Bldg.	Existing 85,000 Sq. ft. SISL Bldg.
• Estimated Cost	$200-250 M	$30 M, Nuclear Energy ($85 M, Defense Programs)
PRODUCTION FACILITY	Fixed Production Capacity, 9 M SWU/y	Phased Production Capacity Adjusted to Market
• Operational Date	1995	1991
• Construction	350,000 sq. ft.	250,000 Sq. ft., first phase
• Estimated Cost	$1,000 M	$500-700M, first phase
• Production	9 M SWU/y	4 M SWU/y, first phase

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Chart 1

In summary, the goal of the SISL effort is to achieve an actual demonstration at three times the projected $20/SWU target (with the exception of complete lifecycle experience) to establish a clear upper limit for AVLIS costs and to have a high confidence basis for achieving the target costs in the production plant.

Question 3. Would you please elaborate on the Atomic Vapor Laser Isotope Separation (AVLIS) engineering work you described?

Response: As indicated in the statement, the extensive engineering work associated with the 1986/1987 demonstration program is very important. This engineering is required to support the detailed evauation of AVLIS economics and to enable a rapid deployment of AVLIS if the demonstration is successful. Details of the proposed engineering work are summarized in the attached charts (Supplementary Charts 2 and 3).

Question 4: Recommendation 2 of the April 30, 1982 report of the DOE Process Evaluation Board's (PEB's) Assessment of the Advanced Isotope Separation Program states: "It is recommended that funds for detailed design and construction of the AVLIS demonstration module not be released by DOE until uncertainties in the design and operation of the uranium collector subsystem are resolved. This will help assure that the DDM is, as nearly as possible, a prototypic plant module." What specific events have occurred since that time, less than a year ago, to now warrant accelerated development of AVLIS? How much enriched uranium has been produced by AVLIS over the past year, and since the process began development?

Response: In response to the concern about collector performance which the PEB raised, a new approach which greatly relaxes thermal control constraints has been verified during the past year. Satisfactory technical resolution of the thermal control issue has thus now been achieved, establishing readiness to undertake the engineering development, scale-up, and demonstration tasks. Details on this point are provided in the classified statement presented in the closed hearing session. As regards the actual SWU production from AVLIS, this has been essentially nil, owing to the technical nature and focus of the program to date and the lack of bulk laser power which will now come from replicating demonstrated laser modules. Of more significance than SWU output to date is the highly successful process verifications

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DWG. NO. K/G-83-120

AVLIS PHASED PRODUCTION FACILITY DEPLOYMENT SCHEDULE

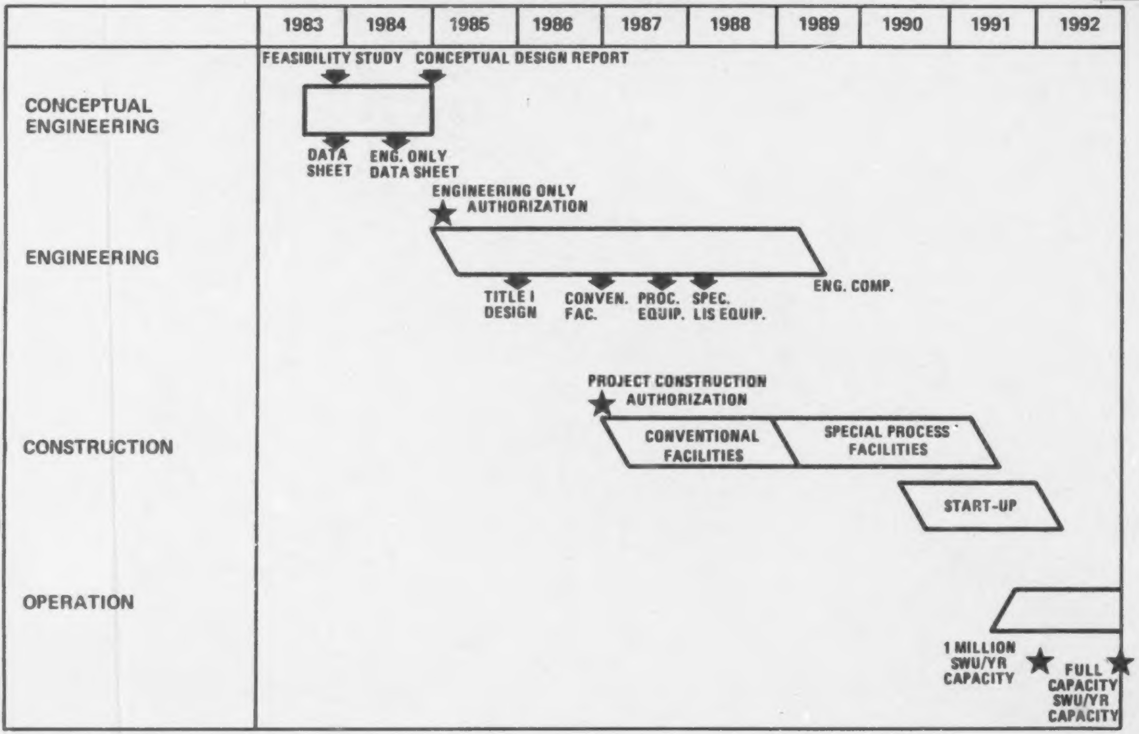

Chart 2

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DWG. NO. K/GT-83-0445

AVLIS PHASED PRODUCTION FACILITY ENGINEERING ACTIVITIES

FY 1983
- $1 MILLION BUDGET
- FEASIBILITY STUDY (BASED ON UF_6 POINT DESIGN – MID FY 1983)

FY 1984
- $3 MILLION BUDGET
- CONCEPTUAL DESIGN REPORT (BASED ON BASELINE DESIGN UPDATE – MID FY 1984)
- PROJECT MANAGEMENT PACKAGE
- ASSESSMENT PACKAGE
- OPERATIONS AND MAINTENANCE PLAN

FY-1985
- $10 MILLION BUDGET (FY 1983 $)
- ENGINEERING ONLY LINE ITEM AUTHORIZATION
- TITLE I DESIGN REPORT
  - CONVENTIONAL FACILITIES– TITLE I, II LEVEL OF DETAIL
  - PROCESS SUPPORT FACILITIES – TITLE I LEVEL OF DETAIL
  - GENERAL LIS EQUIPMENT – TITLE I LEVEL OF DETAIL
  - SPECIAL LIS EQUIPMENT – CONCEPTUAL LEVEL OF DETAIL

FY –1986
- $26 MILLION BUDGET (FY 1983 $)
- CONVENTIONAL FACILITY DESIGN COMPLETE
- PROCESS SUPPORT FACILITIES – TITLE II DESIGN START
- GENERAL LIS EQUIPMENT – TITLE II DESIGN START
- SPECIAL LIS EQUIPMENT – TITLE I DESIGN START

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Chart 3

which have been achieved. The keys to an economically attractive AVLIS process are (1) ability to produce high throughput, high quality uranium vapor at reasonable cost; (2) ability to produce high precision, high average power laser photons at reasonable cost; (3) ability to achieve efficient photoionization when the photons and atoms are combined; and (4) the ability to manage the uranium flows effectively. Each of these process elements has been technically validated. Additional details are also provided in the classified statement.

Question 5. It has been suggested that improved rotor and suspension system components now under development for the centrifuge can greatly enhance not only the production capacity, but also the reliability of the Gas Centrifuge Enrichment Plant (GCEP). How might these developments influence the comparisons between the Advanced Gas Centrifuge (AGC) and the Advanced Vapor Laser Isotope Separation (AVLIS) technologies? In other words, how cost competitive are the two technologies expected to be?

Response: The improved rotor and suspension system components now under development have the potential of simplifying the centrifuge machine design, thereby reducing procurement costs, and improving reliability, thereby reducing operating costs. The development efforts for these particular machine modifications are at a relatively early stage, and cost studies for these potentially important improvements are incomplete at this time. Most of the advanced gas centrifuge R&D effort is currently aimed at improving centrifuge machine capacity, and this work is proceeding well.

Question 6. What are the roles of the various participants, particularly the Centrifuge Manufacturers (CMs), in the Advanced Gas Centrifuge Program?

Response: In the Advanced Gas Centrifuge (AGC) Program, the primary roles of Centrifuge Manufacturers (CMs) center on centrifuge rotor tube development, including manufacturing development. CMs also function as designers of non-rotor components, suppliers of test hardware, and testers of machine designs. The University of Virginia (UVa) focuses on theoretical and experimental studies directed mainly toward improving centrifuge separative efficiency, but UVa also works in the materials area. The

Lawrence Livermore and Los Alamos National Laboratories contribute mainly in the area of gas dynamic theory with the former also contributing in the rotor materials area and the latter in the scoop development area. UCC-ND has a broad development program covering virtually all technical (non-manufacturing) areas, serves DOE as lead AGC contractor by coordinating AGC program activities and technical evaluations; serves as design integrator; performs a large fraction of the machine testing, and contributes in a number of specific technical areas.

Question 7. What are the primary technical impediments to the successful development of the Set V Advanced Gas Centrifuge (AGC) machine?

Response: At this time, we do not perceive any technical roadblocks to achieving the Set V goal of performance that is between 2 and 3 times higher than that of the Set III machine. There are some specific technical requirements in the areas of rotor materials design and gas dynamics, however, that will determine, based on how they are resolved, precisely where in the 2X-3X range the performance will eventually be. The goal, of course, is the 3X machine. In general terms, the requirements that are of most concern today center on the stability of rotor material and process gas at very high speeds.

1984 DEPARTMENT OF ENERGY AUTHORIZATION

THURSDAY, MARCH 17, 1983

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research and Production,
Washington, D.C.

The subcommittee met, pursuant to notice, at 9:35 a.m., in room 2325, Rayburn House Office Building, Hon. Tim Valentine (acting chairman of the subcommittee) presiding.

Present: Representatives Valentine, Lloyd, Walker, Winn, and Chandler.

Mr. Valentine. If you will give me your attention, please, the subcommittee will come to order, in the hope that sometime during your presentation we will fill in some of these seats. However, after all, except for the chairman you have the two most important people on the committee here.

I want to welcome all of you to this hearing this morning where we will receive testimony on the Department of Energy's fiscal year 1984 budget request for electric energy systems, energy storage, and small-scale hydroelectric systems.

Without objection, our proceedings today may be covered and recorded by the media and other persons.

The United States has been a world leader in developing systems which benefit our citizens. Systems for reliable electric power delivery are commonplace in this Nation, but there is a need to continue R&D activities to provide for expanded distribution, including higher voltage transmission capability for transferring major quantities of power from one network to another. There is a need to carefully investigate the biological effects that these high voltages might have on humans and other creatures.

World conditions force us to investigate the effects of electromagnetic pulses on our transmission and distribution systems. New materials and new control techniques are also needed for higher efficiency distribution, and consequently for providing electricity to consumers at the lowest possible cost.

In the storage area, we hope to continue to provide for systems which will make dispersed solar generating systems economical and which will enable our automobile manufacturers to offer electric vehicles as a quiet, pollution-free, low-cost alternative to gasoline powered cars.

Activities in thermal storage and superconducting magnetic energy storage will also be reviewed.

Our first witness today will be Mr. Joseph J. Tribble, Assistant Secretary for Conservation and Renewable Energy. Following Mr. Tribble, we will hear from a panel of witnesses including Mr. Arnold Frickett, director, Advanced Conversion and Storage, Electric Power Research Institute [EPRI]; Mr. Lowell Endahl, manager of Research and Technological Development, National Rural Electric Cooperative Association; Mr. Donald J. Helfrecht, president, Madison Gas & Electric Company and Wisconsin Electric Utilities Research Foundation; and Mr. Lester H. Fink, president, Systems Engineering for Power, Inc., representing the Institute for Electrical and Electronics Engineers.

Before we begin receiving testimony, I would like to call upon the distinguished ranking Republican member of this committee, if he has any voice left after last night. Mr. Walker?

Mr. **Walker**. Thank you, Mr. Chairman, and thank you particularly for this opportunity to welcome our witnesses to this hearing. We look forward to hearing from both the DOE personnel and the people from outside DOE as they discuss the electric energy systems, energy storage systems, and small-scale hydroelectric systems programs.

Probably we all agree that these programs are extremely difficult to characterize. This difficulty becomes more realistic as the amount of money available for such programs is curtailed. It is necessary to fall back from a position of demonstrating on some large scales and spending the few dollars available on basic and fundamental research with some application involved.

A case in point is the small-scale hydroelectric systems program. Such a process has been around for a long time. Surely there are improvements that can be made in the components of such a system, but they would be of a cosmetic rather than a fundamental nature, so we must raise some questions about the R&D value of this program, in my opinion.

The electric energy systems and the energy storage system programs do not quite fall into the category of hydropower programs. These energy systems programs could involve more basic concepts, and could therefore substantiate the use of our limited funds. Probably one must look at these programs on a case-by-case basis.

We look forward, Mr. Chairman, to hearing from our witnesses today. In the discussions we hope to learn of some successes gained from these programs. No doubt such accomplishments can point to the continuation of these programs at some scope in the future.

Thank you, Mr. Chairman.

Mr. **Valentine**. Thank you, sir.

Mr. Tribble, we appreciate your coming here with your colleagues. We welcome you and are ready to hear from you at this time. You might want to summarize your presentation with the assurance that the prepared material, which you have presented to us here or will present, will appear in the record.

STATEMENT OF JOSEPH J. TRIBBLE, ASSISTANT SECRETARY, CONSERVATION AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY, ACCOMPANIED BY AL LANDGREBE AND RAY DUNLAP

Mr. **Tribble**. Thank you, Mr. Chairman.

I welcome the opportunity to appear before you today to discuss the proposals that we have put forth in the fiscal 1984 budget for conservation and renewable energy programs under the jurisdiction of this subcommittee.

In accordance with congressional direction, the fiscal year 1984 conservation budget is submitted on the basis of end-use sectors rather than the more generic categories which characterized the fiscal 1983 request. The details of each of these sectors is covered in my testimony, which is submitted for the record. I would like to make a few general comments.

First, the U.S. energy supply situation is more favorable this year than it was at this time last year. Recent figures indicate that net imports of petroleum into the United States, excluding strategic petroleum reserve imports, are now down to 4 million barrels per day. Considering the deliveries of petroleum to the United States from Mexico, Venezuela, and the North Sea, we as a nation are far less vulnerable to disruptions in the Arab OPEC nations than we were previously. The oversupply of oil is putting pressure on prices, as seen in recent reductions.

Second, there are now more than 300 million barrels of oil in the strategic petroleum reserve.

Third, efforts to improve the efficiency with which energy is used are continuing, and the results of past efforts continue to pay dividends.

These favorable circumstances should in no way minimize the importance of conservation. Falling energy prices put an additional burden on the Department to highlight the importance of continuing conservation and renewable energy programs. As a nation, we should not conclude that short-term changes in prices or supply lead to reduced need for conservation and renewables.

Generally, a timeframe of from 10 to 15 years is required before the results of research find their way into widespread use. Conservation and renewable energy research which is done now will be very beneficial in the years to come, when the price of energy will surely be higher.

You mentioned the gentlemen who will follow in the panel, and I would like to say that the relationship between the Department of Energy and the organizations that are represented by these gentleman has been very good. We enjoy a very close working relationship. We jointly fund some projects; and we will be very interested in their comments on our program.

What we are trying to do is to work closely with the industry, determine where there are gaps in research between what the private sector is doing and what needs to be done, so that the Federal Government may participate in those types of activities if in fact it is in the national interest. One of the things that we particularly would be interested in are specific recommendations, if there are any, above and beyond those programs that we do propose for the fiscal 1984 budget.

Mr. Chairman, that would conclude my introductory remarks. I would be pleased to respond to any questions that you have.

[The prepared statement of Mr. Tribble follows:]

Testimony of

JOSEPH J. TRIBBLE

Assistant Secretary

Conservation and Renewable Energy

Before the

Subcommittee on Energy Research and Production

of the

House Committee on Science and Technology

March 17, 1983

Authorization - R&D for

Electric Energy Systems, Energy Storage,

and Hydropower

Madame Chairman and members of the Subcommittee, we welcome the opportunity to meet with you again to discuss the proposals we have made in the FY 1984 budget for Conservation and Renewable Energy programs. In accordance with Congressional direction, the FY 1984 conservation budget is submitted on the basis of end-use sectors rather than the more generic categories which characterized the FY 1983 request. We will cover the details of each of these sectors; however, some general comments are appropriate. First, the U.S. energy-supply situation is even more favorable this year than it was at this time last year. Recent figures indicate that net imports of petroleum into the United States (excluding SPR imports) are now down to 4 million barrels per day. Considering the deliveries of petroleum to the United States from Mexico, Venezuela, and the North Sea, we as a Nation are far less vulnerable to disruptions in the Arab OPEC nations than we were previously. The oversupply of oil is putting pressure on prices, as seen in recent reductions. Second, there are now more than 300 million barrels of oil in the Strategic Petroleum Reserve. Third, efforts to improve the efficiency with which energy is used are continuing, and the results of past efforts continue to pay dividends.

These favorable circumstances should in no way minimize the importance of conservation. As Secretary Hodel has himself stated in testimony, we are well aware of the fact that falling energy prices put an additional burden on the Department to highlight the importance of continuing conservation and renewable energy programs. As a Nation, we ought not to conclude that short-term changes in prices or supply lead to reduced need for conservation and renewables. The Federal Government should provide at least sufficient high-level interest and support for conservation and renewable activities to maintain the momentum achieved thus far. Generally, a time-frame of from 10 to 15 years is required before research finds its way into widespread use. Conservation and renewable energy research which is done now will be very beneficial in the years to come, when the price of energy will surely be higher.

ELECTRIC ENERGY SYSTEMS

The Electric Energy Systems program is concerned with electric field effects, power delivery reliability and systems technology. We have requested $12.6 million for this work in FY 1984. With these funds, we would expect to continue biological research on the potential to animals and humans of ultrahigh voltages in transmissions systems. We would complete the design verification of the deepwater submarine cable for potential use between islands in Hawaii, and would continue research in solid and gaseous electric materials breakdown mechanisms and fiber optics for power system use. Direct current power transmission has some advantages over alternating current transmission. However, the switchgear for use with high voltage DC lines is not perfected. DOE is exploring means whereby a DC circuit can be fed from more than one source, and power distributed from it to more than one demand.

ENERGY STORAGE TECHNOLOGIES

Storing energy has proven to be an elusive undertaking. From FY 1977 through FY 1983, the Federal Government has spent approximately $335 million on attempts to find a suitable means of storing both mechanical and electrochemical energy. Some progress has been made, of course. However, we are sill working on a means to store adequate energy to drive an automobile 100 miles. For FY 1984, we have requested $14.2 million. With these funds, we would expect to continue research on sodium/sulfur batteries, zinc/halogen batteries and aluminum/air batteries. We will also attempt to learn more about the basic interaction between electrodes and electrolytes.

HYDROPOWER

The original objective of the Hydropower program was to help reestablish a vigorous small hydro industry. The technology is now inherently suitable for development by non-Federal public and private sectors.

Program accomplishments have included 20 demonstration projects to identify technical, financial, environmental and regulatory barriers. Eight of these projects are currently on line. Twenty engineering R&D projects have also been completed and nine more are underway. Through the program, 40 States have received technical and/or financial assistance for resource inventories, updating regulatory and administrative procedures, implementing PURPA requirements and developer workshops.

In FY 1983, the Hydropower program continues to provide technical monitoring and support for previously-funded DOE loans, demonstrations, and R&D projects. Field research on minimum streamflow requirements will be completed. Previously funded projects included the marine thruster, Schneider engine, prefabricated systems design, micro-hydro handbook and the pumps-as-turbines profile. Research is also being conducted on a variable-speed generator for ultra-low-head hydropower.

No funds are being requested for FY 1984 since hydropower technology is mature and market-ready. It is believed that program R&D activities and demonstration projects have provided sufficient information and technical knowledge to stimulate the small hydro industry and potential users to pursue market activities.

Madame Chairman, this concludes my statement. We will be glad to answer any questions you may have.

Mr. VALENTINE. Well, thank you very much, Mr. Tribble. I have some questions, very few.

Mr. TRIBBLE. All right, that would be fine.

Mr. VALENTINE. I think that we certainly seem to be a country of peaks and valleys in the way we consider problems and the way we look at solutions sometimes. You know, we get in a rush and we move the pendulum one way and then back the other way. I think, as you pointed out, that we have been successful in the conservation of energy and energy sources over the past several years because of the threat that the people who have the oil would tighten the grip that they had around our throats. Now that oil prices would seem to be on the decline, are you able to detect any loosening of our resolve in this area of conservation?

Mr. TRIBBLE. I think there would be a tendency on the part of the public to do so if the price of oil comes down substantially further. I believe that the conservation measures that have been taken will continue to pay dividends over time.

We now have automobiles coming into the fleet that have much better fuel economy than those that we had in 1973. I think this is going to continue, and the fleet average miles per gallon is continuing to increase over the years.

In the industrial sector, a number of economies have been made that will continue to pay dividends. In the 10 most energy-intensive industries, in the last 10 years since the oil crisis, industry has reduced energy consumption per unit of production by 20 percent. I am sure that we will not only continue to see this improvement, but other improvements will take place as the capital expenditures that have been authorized in recent years are implemented.

The same thing is true in the residential sector. Where the price of energy has increased, it has caused us all to take another look at our houses. We have put in a lot of attic insulation; we have done a number of things that do enable us to use less energy in our homes. These benefits will continue.

The program that we have before us is one in which we feel that we, the Federal Government, should concentrate on research and development which will provide the private sector with additional knowledge on ways by which energy can be used more efficiently. That is the aim of the programs that we have proposed. We do not want to experience any reduction in our emphasis on conservation or research for renewable energy.

Mr. VALENTINE. Do you detect any pressures within the Government, within the executive branch of the Government, that you are in a position to comment on that would indicate to your mind a retreat from past policies, a past awareness which I think that all branches of the Government have attempted to implement, to move us into development of alternate sources of energy and to keep up the programs which can be so helpful, coming from the Government, to remind people of the necessity to conserve.

Mr. TRIBBLE. Of course, we are all aware of the pressures on the Congress and the administration to cut back on overall expenditures because of potential deficits. We do recognize this, of course, and we are trying to make the best use of the dollars that we do have available. That really is the only pressure that I see.

Mr. Valentine. It has been my feeling here, like many other times, that the key to this business of getting control of the deficit and changing the fiscal policies of the Federal Government is for everybody to share in the responsibility of getting by with less, or to be sure, as somebody said, that everyone's ox is appropriately gored.

Do you think your ox has been satisfactorily gored? How does your budget request for fiscal year 1984 compare to what you had to spend for 1983, this year, and for 1982?

Mr. Tribble. The dollars that we have proposed for the fiscal year 1984 budget are far lower than the dollars which were appropriated for 1983. On the other hand, they are considerably higher than our request for fiscal year 1983, and this is in recognition of the fact that the Congress did not agree with our proposals in 1983. We have recognized that and we have submitted for 1984 a proposal that we think does cover the major places where we should be doing research and development.

Mr. Valentine. Thank you very much.

I would like to recognize at this time Mr. Larry Winn, the ranking minority member of the full committee, for whatever statements or questions that he might have.

Mr. Winn. Thank you, Mr. Chairman.

I missed your testimony and I haven't had a chance to read the advance on it, but just as far as conservation is concerned, and renewable energy and the subject matter that comes under your jurisdiction, there has been for the last several years a tremendous amount of pressure to spend more money on that. At the same time, there has been the old argument that after the Federal Government does a lot of the research and some of the early development, it is time for private enterprise to take over those jobs. Which direction are we headed now?

Mr. Tribble. Over time, in the last couple of years, we have made a vigorous attempt to convert our program from one of demonstration and commercialization of known technologies to a research program. Certainly, we have made progress, as seen in the results of the research done in the past, and there does come a time when that needs to be taken over by the private sector.

In conservation, many of the things that have been done were not the result of research but were things which we knew how to do, although we really didn't have the economic incentive to do so while the price of energy was quite low. The industrial sector has particularly been one to recognize this, and, as the price of energy has gone up, they have taken those measures which they already know how to do.

There do remain, however, some research activities that we think are worthwhile. In the field of electric transmission, in the field of generation, there is still much progress that needs to be made, and we are aiming our efforts at making those improvements.

Mr. Winn. Storage batteries come under your jurisdiction, don't they?

Mr. Tribble. Yes.

Mr. Winn. What kind of strides are you making in that field?

Mr. TRIBBLE. The development of electrochemical storage has been a very elusive goal. We have spent millions of dollars on development of various types of batteries. We have, of course, made substantial progress.

The lead-acid battery that we are familiar with for our automobile use has been adapted, or an attempt has been made to adapt it, for use in an electric vehicle. Characteristics of a lead-acid battery for vehicular propulsion are quite different from those required to simply start an internal combustion engine, and developments along that line have taken place.

We have investigated a number of other type batteries. The nickel-iron battery is one in which General Motors has a high degree of interest. We think that it has potential. On the other hand, nickel is expensive. Whether it can become economical is a question.

We are currently working on sodium-sulfur batteries, which do show promise. We are also working on flow batteries, zinc-bromine, zinc-chlorine. We have limited progress to report but we feel that it would be very much in the Nation's interest to develop the capability to store electrical energy, if we can do so economically.

We are coming forth with technologies such as photovoltaics, wind machines, and technologies that will produce electric power when the resource is available, and that is not necessarily when the demand is there. If we could provide an economical means of storing that electrical energy so that we could extend the useful time through which a wind machine or a photovoltaic array could be used, then we think this is a proper development.

This is one of the reasons why, I believe, in the 1984 proposal we have something on the order of $19 million for electrochemical storage research. Part of this is in our transportation sector and part of it is under the storage sector.

Mr. WINN. Well, let me interrupt you right there. Up until the last year or so we had a parade of various vehicles coming to Capitol Hill to take Members of Congress for rides, with all these new kinds of storage batteries and things, and variations of cars that could go from diesel to regular gas in fuel. All of a sudden, what happened to that? The Federal Government was a participant with the private sector. Now we don't care about the free rides. We would like to have something for our money. Where are we on those things? They are just almost dead, it seems to me.

Mr. TRIBBLE. We found in the development of the electric vehicle that the need for a battery was the primary concern. We were able to develop the drive train and, of course, the vehicle itself was easy to come by. We have a hybrid vehicle that is now ready for tests, and it will be tested.

Mr. WINN. Is that the unit that the post office bought? They bought, if my memory serves me correctly, about 200 units, electric car type of units.

Mr. TRIBBLE. Yes. That was straight electric, is my understanding.

Mr. WINN. That was a straight electric car, but I thought part of that was the research part on developing a battery that would take somebody more than 40 or 50 miles.

Mr. TRIBBLE. That's right.

Mr. WINN. What happened to it? That is what I am trying to find out.

Mr. TRIBBLE. All right. When I came on board——

Mr. WINN. It must not have worked because the Postal Service is not very good these days. [Laughter.]

Mr. TRIBBLE. We have a user group which is comprised of various fleet operators who are testing these vehicles. That fleet initially was envisioned to be some 1,100 vehicles. It has come down substantially now. I believe the number active in the fleet is on the order of 650, but these fleet operators are using these electric vehicles and as they develop problems, they are telling us about it and we are trying to find a solution to them.

Mr. WINN. They are doing the research?

Mr. TRIBBLE. They are really doing the testing and presenting the problems to us, and we are trying to do the research to overcome them.

The level of effort is substantially lower now than it was, and there were a number of other activities to promote the electric vehicle, such as the loan guarantees. Unfortunately, there has not been a demand for electric vehicles. The companies that thought they would be able to respond to this demand have not been able to make a financial success of it.

At the current time, we feel that the only appropriate activity relative to the electric vehicle is to continue to work on the development of batteries, plus a drive train component which is being developed by General Electric Co., with Ford, I believe, on a concentric axle alternating current motor, which will give us a better drive characteristic. That is the reason for our reduction.

Mr. WINN. Are we spending a lot of money now on a technology that is still very much up in the air? Of course, the electric car is no great discovery. Way back in the thirties we had those. We haven't developed a battery that really will take us more than about 50 or 60 miles.

Mr. TRIBBLE. That is right.

Mr. WINN. Now with the price of gasoline coming down and the availability of regular and unleaded gas and diesel fuel, are we continuing up a blind road with research as far as expenditures of funds from DOE?

Mr. TRIBBLE. We are certainly trying to avoid that. We are cutting back on the number of different types of batteries that we are working on, and we have limited it to the ones that we think are the most likely to be successful.

Mr. WINN. What about the work that the Federal Republic of Germany is doing in the battery field? I believe Japan is also doing some work in that field. Are we working with them or are we all going our own way?

Mr. TRIBBLE. I am personally not familiar with that but I have a gentleman with me who is, and I would like to ask him to respond to that.

Mr. WINN. Surely, if you will just acknowledge him and introduce him so that we can have his name.

Mr. TRIBBLE. Yes. Dr. Al Landgrebe is in our shop, and he knows a great deal more about this than I do.

Mr. LANDGREBE. With respect to Germany, a program on batteries for electric vehicles does exist. I guess the rationale with the Federal Republic of Germany is that gasoline may be so expensive in the future, that if they want to visit their grandchildren they are going to need an electric vehicle.

Mr. WINN. Well, it is a lot more expensive than it is here.

Mr. LANDGREBE. That is right.

Mr. WINN. Over twice, I believe.

Mr. LANDGREBE. Yes. The main effort is on high-temperature batteries, with the majority of the effort going into sodium-sulfur batteries. This is being developed by Brown-Boveri.

Mr. WINN. By what?

Mr. LANDGREBE. Brown-Boveri is the name of the company.

Mr. WINN. Brown-Boveri?

Mr. LANDGREBE. Yes. There is a smaller effort, some work on lithium-metal sulfur which is being done at Battelle in Frankfurt and by Varder Battery Co. The total German effort is about, I guess, $22 million, with most of that going into the——

Mr. WINN. What is ours?

Mr. LANDGREBE. Our effort is about comparable.

Mr. TRIBBLE. Proposed, about $19.4 million, I believe.

Mr. WINN. What about Japan? We are all allies and——

Mr. LANDGREBE. Well, Japan over the years has had two programs on batteries. The first program was with respect to electric vehicles, and the rationale for that was pollution.

Mr. WINN. Yes?

Mr. LANDGREBE. Essentially that has been given to a trade association, and I don't quite understand the semiofficial type of government involvement now.

Mr. WINN. Yes. I understand it.

Mr. LANDGREBE. The other effort is on a project which is done through the equivalent of the Japanese EPRI and the Japanese Government. It is called Project Moonlight, and it is a 10-year effort to develop batteries for load leveling. It is really the mirror image of our program. They picked the same systems that we were developing—zinc-bromine, zinc-chlorine, sodium-sulfur, redox, and lead-acid—all the things we had in our program. They have come over, we have talked to them, and they——

Mr. WINN. They will sell them back to us shortly.

Mr. LANDGREBE. Yes, they may.

Mr. WINN. How much money are they spending?

Mr. LANDGREBE. They are spending at the level of about $1[illegible] million a year, but there is 50-50 Government involvement, so it is about the same.

Mr. WINN. Yes. Yes, they have a subsidy type of thing.

Mr. LANDGREBE. Yes.

Mr. WINN. Thank you very much.

Mr. LANDGREBE. You are welcome.

Mr. WINN. Thank you very much for the time, Mr. Chairman.

Mr. Tribble, just one more question in the conservation facet of your jurisdiction—of course conservation was around long before the Department of Energy and will be long afterward, probably—isn't it a matter, with many of those programs, of educating people how to conserve and what to conserve?

Mr. **Tribble**. To a very large degree that is true. We know how to build buildings that can be comfortable in severe climates, even without substantial heating systems. We have known of measures that could be taken by industrial concerns to make substantial improvements. The automotive industry demonstrated that, under the circumstances of demand, they could produce automotive transportation that was much more economical.

On the other hand, there are still some things that we do need to learn, that we are working toward. However, back to your basic assumption: Yes, conservation is largely a matter of education and using the technologies that are known, and a great deal of this is taking place in response to the increased cost of energy.

Mr. **Winn**. Thank you very much.

Thank you, Mr. Chairman.

Mr. **Valentine**. Thank you, sir.

I want to recognize Mr. Chandler, but before I do that, one or two questions in line with what Mr. Winn had asked you: Can you comment on any significant research and development efforts that are currently going on in the private sector? If there are efforts of significance, is there any liaison between your organization and these private companies, exchanges of information and that sort of thing?

Mr. **Tribble**. Yes. Throughout all of the programs that we are involved with, we make an effort to maintain contact with the industry involved, and a tremendous amount of research is being done in the private sector. The Electric Power Research Institute, whom you will hear from later today, is one organization which is doing a substantial amount of research work. We are working with them.

We are doing this with all segments of the renewable energy industry. It is difficult for us to know, in terms of dollars, how much research is being done by the private sector because a great deal of it is being done on a proprietary basis. We want to maintain good relationships and close communication so that we will not be competing with them on things that they are doing on a proprietary basis, and we certainly don't want to be reinventing a wheel that they have already invented.

However, the solar industry, for example, is now in excess of $1 billion a year and growing quite rapidly. Some of the participants in that field are taking over substantial research and coming forth with developments on their own.

I am sorry; I don't know that I have given you a complete answer to your question. If there is any part of it that I haven't covered, I would be glad to try again.

Mr. **Valentine**. Thank you, Mr. Tribble.

Let me recognize Mr. Chandler next. We are glad to have you, sir.

Mr. **Chandler**. Thank you, Mr. Chairman.

I thought Mr. Winn's questions were really right to the point, and they are very relevant to the area of the country I come from. In the Pacific Northwest we have lots of water most of the year but an awful lot in the spring. Figuring out some way to store and then utilize the energy from that throughout the year would be a great breakthrough for us.

In addition to that, we have—as you are probably aware—the Northwest Regional Power Planning Council——

Mr. TRIBBLE. Yes.

Mr. CHANDLER [continuing]. Which is issuing a draft report or has issued a draft report which I read, that calls for the conservation of energy to something nearing the level of about a third of what is being produced in the region right now. It has people from the private—and I think probably public, too—utility systems scratching their heads and wondering how on Earth are we ever going to be able to do this. As Mr. Winn's questions certainly pointed out, conservation is not free. It is a cost that you decide; you have to measure, is it more economical to do that than it is to generate the power, and so forth. What is your role there?

Mr. TRIBBLE. As you know, there are three major interties between the Pacific Northwest and the Southwest: two alternating current lines and one direct current line. One of the projects that we have in our electric energy systems program is to improve direct current switchgear.

At the present time, the technology has not been adequately developed whereby we can feed into an intertie from several different sources of direct current power, nor can we take away from that intertie at different points of demand. We have to convert to direct current and transmit to a location, convert back to alternating current and transmit from there. We are working toward the development of switchgear that will permit us to have more flexibility in a direct current line. That is one of the areas.

The question of storage in that vicinity, as you are quite well familiar, is a very difficult problem on account of the lack of storage capacity behind the dams relative to the streamflow. We have done some work in developing various types of storage whereby we could use that power when the water is available and store the electricity, not in terms of electric power but, for example, in a form of underground compressed air storage.

EPRI has picked up on that and they are now going forward with that. With this system, you compress air and store it while the water is available; then you run it back through a turbine, regenerate electricity during peak hours or when the water is not available. However, we do not have any technology at this time that is to any degree satisfactory in storing the quantity of energy that we would need to store in order to level the demand in the Pacific Northwest.

Mr. CHANDLER. Just one final question, Mr. Chairman, if I may. That concerns small-scale or low head hydro projects. I see considerable potential there. How much have we spent on that alternative and what, in your view, did we get for our money with that expenditure?

Mr. TRIBBLE. Of course, the technology for hydropower use has been with us for many, many years, and it was not until the price of energy increased dramatically that attention was turned to the small hydropower facilities that could be built. The PURPA law was another influence that came along at about that time, which provided that a small power producer could tie into an electrical grid.

There are problems with this, economic problems primarily. I would say there are virtually no technological problems with this, but under PURPA the small power producer must pay for the cost of getting the power that is generated to the grid, which includes the transmission line, the switchgear, and the transformer to tie into the grid.

You do not find many good hydro sites that are close to the electric power grid system, and so the economics mitigate against many of the sites. On the other hand, there are a large number of sites that could be developed that are relatively small, and I am thinking in terms of around 30 megawatts capacity. When the economics are right, these sites can be developed.

The work that we have done in small hydro and low head hydro has certainly focused attention on the fact that that is a possibility. We did have a loan guarantee program. We did make a number of loans and we are monitoring those. We have learned and have disseminated the information we know about the utilization of small-scale hydro. We feel that we have reached the point where we really cannot do anything more that is productive.

One of the things that we are working on in 1983 is research on streamflow and how it affects the aquatic life in the stream. In many instances, this is such a site-specific problem that we have not yet been able to come up with generalities that would apply.

The development of equipment is something that we have said that we would do in fiscal year 1983, simply because we were told to spend another $1 million, and we are going to be looking into the opportunity to assist in developing a variable-speed generator. Further, we are looking at the possibility of developing a lower-cost low head hydro turbine. We feel that there is probably not any new technology involved here, but we are going to try to find out if there is, and that is where we will focus this effort.

Mr. CHANDLER. Thank you for your—

Mr. TRIBBLE. From fiscal year 1977 through fiscal year 1983, the Federal Government has spent $62.4 million on small hydro.

Mr. CHANDLER. Thank you, sir.

Thank you, Mr. Chairman.

Mr. VALENTINE. Mr. Tribble, as everybody knows we have in this great Nation a petroleum industry that is gigantic and very helpful and very powerful. It has, thank goodness, contributed mightily to the position of preeminence that we occupy in the world and to many of the comforts that we enjoy.

Do you detect, in your operation and your attempt to develop this automotive battery, any subtleties from that industry? Are you conscious of any efforts on the part of the petroleum industry to assist you in the development of this battery or to impede in any way your progress?

Mr. TRIBBLE. Certainly there is no evidence that has come to my attention of any effort to impede our progress. I would have to check with my people to see if we are in fact working with any of the petroleum companies. I know that we are working with the automobile companies and the battery companies in the development of batteries.

Excuse me just one moment.

Mr. LANDGREBE. We have been working with Exxon on a zinc-bromine battery for electric vehicle and solar and load-leveling applications, in a cost-shared, 50–50 arrangement with them.

Mr. VALENTINE. Is that, in your opinion, a satisfactory relationship?

Mr. LANDGREBE. Yes.

Mr. VALENTINE. Is it beneficial?

Mr. LANDGREBE. I think it is a good relationship. We have a very good relationship with the automotive companies, with Ford and General Motors. They review our program and they participate in our program and there is an interest in it.

Mr. VALENTINE. Do either one of you have a prediction as to how far away we are from a workable battery that will get us further than 60 miles or so?

Mr. LANDGREBE. Well, the sodium-sulfur battery, the first one for an electric vehicle is being constructed now. If the test goes correctly, the decision will be made whether to integrate it into a vehicle this summer, and then it would go to Ford and not be driven on the road but driven on their test track.

This system, the dummy battery and some live cells, was driven around the test track to determine the type of forces it would encounter. We have taken cells and accelerated them up to something like 9 G's, and so it looks like it is feasible. This is a first, one-of-a-kind, that we are putting together. With luck, we will have some results on in-vehicle testing through the transportation program sometime this fall.

Mr. VALENTINE. Mr. Tribble, the Department of Energy has submitted a plan for implementing the continuing resolution which did not include superconducting magnetic energy storage work at the University of Wisconsin. Can you comment on that or explain it?

Mr. TRIBBLE. Yes. We have for several years been involved in the development of a superconducting magnetic energy storage device. It is actually being tested now at Bonneville Power Administration but this is a small, 10-megawatt unit that is designed primarily to shave spikes in the electric current that are the result of harmonics.

As I understand, a study has been made of the potential of the superconducting magnetic storage technology. The cost is extremely high. If all of the problems are solved and things fall in place in an ideal fashion, the cost of this type of energy storage would still not be competitive with current technology.

For that reason, we have felt that until there is a breakthrough in materials that have a larger capacity for electrical storage, we should not go through with that project. We just simply think that it is not a wise investment.

Mr. VALENTINE. Thank you, sir.

Mr. Winn, do you have anything else?

Mr. WINN. No.

Mr. VALENTINE. Mr. Chandler?

Mr. CHANDLER. No, thank you.

Mr. TRIBBLE. Mr. Chairman, may I make one other comment before I conclude?

Mr. VALENTINE. Yes, please do.

Mr. **Tribble.** I brought with me today a piece of electrical cable. One of the projects that we have underway is work on an electrical cable which is intended to be used between the islands in Hawaii. This is a project that we have spent some money on, in the design, but I would like for you gentlemen to see the kind of thing that we are working with and some of the problems that we see. It may be that we will need to alter the direction that this program is going in until we can get some more design information behind us.

Mr. **Valentine.** Is that the cable, Mr. Tribble, the deepwater one to be installed between the islands?

Mr. **Tribble.** Yes, that is right.

Mr. **Valentine.** Does that—not that there is anything wrong with it—does that have any other use that you know of? Could it be used in any other State in the Union?

Mr. **Tribble.** The only place I know where this would be applicable would be in the trough between two of the islands of Hawaii where the depth is, I understand, 7,000 feet. The distance is 150 miles.

Now this, I believe, is a prototype cable that is for use in some 200 feet of depth. This weighs about 50 pounds per foot, and this is the current-carrying portion of the cable. This is the insulation. There are a number of other layers in here to carry the strength, to give tensile strength to the cable.

Now this cable, by virtue of this configuration, cannot stand torsion. The project that we have is to develop a cable that we can string out 150 miles and release to a depth of 7,000 feet. We cannot let it twist, and the radius within which we can bend it is very limited; it has to be a long radius.

We are concerned that until we can design some additional flexibility into this—well, we feel like that is one of our next challenges. It is like having a 150-mile-long eggshell. It is that fragile, from the standpoint of torsion and twisting.

Mr. **Valentine.** How much money has the Government spent on this project?

Mr. **Tribble.** How much have we spent on this so far, about $3 or $4 million?

Mr. **Dunlap.** It was $1.2 million last year, and $4.8 million in the 1983 program, and another million in the 1984 budget.

Mr. **Valentine.** How many feet of that cable have you put together?

Mr. **Tribble.** This is still in the design stage.

Mr. **Valentine.** What would it cost? Is this it? Is this what we got?

Mr. **Tribble.** This was not developed with that.

Mr. **Valentine.** Could you leave that with us? [Laughter.]

What would it cost to make that thing long enough to go between those islands?

Mr. **Tribble.** Do we have any figure on it?

Mr. **Valentine.** Do you have anybody in your organization that can count that high? [Laughter.]

Mr. **Dunlap.** I think a rough estimate for actual construction and installation is on the order of $400 or $500 million. That would be done by the private sector.

Mr. **Valentine.** How many people live on these two islands?

Mr. TRIBBLE. Well, the objective is to generate the power from geothermal resources on one of the islands and to transmit the power to the island of Oahu where the majority of the population is. The development of the geothermal resources is another major expenditure.

Mr. WINN. How does this compare with the cable that goes between the main islands of New Zealand?

It is my understanding from staff that they pick up their power at the South Island and send it to the North Island through a cable, an underwater cable.

Mr. TRIBBLE. Underwater cable is not anything particularly new. We are planning to build in the Alaska Power Administration an underwater cable that will connect a number of the cities in southeastern Alaska. However, to design a cable that will withstand these depths and the tension that is required is the real problem here.

I just thought it would be a good idea for you to see what we are up to.

Mr. VALENTINE. That thing is heavy. You ought to have a staff man carrying that thing around. [Laughter.]

Mr. VALENTINE. Well, Mr. Tribble, we thank you very much, sir. We invite you to stay with us, whatever you desire.

Mr. TRIBBLE. Thank you, Mr. Chairman.

Mr. VALENTINE. Thank you, sir.

We are ready for the other gentlemen now, in such order as they deem appropriate. I guess you would all want to sit together.

Welcome, gentlemen. We are glad to have you. You might want to summarize your testimony. The written statements, we assure you, will appear in the record en toto. We are ready. Mr. Fickett?

STATEMENT OF ARNOLD P. FICKETT, DIRECTOR, ADVANCED CONVERSION AND STORAGE DEPARTMENT, ELECTRIC POWER RESEARCH INSTITUTE, ACCOMPANIED BY JOSEPH PORTER, ELECTRIC SYSTEMS DIVISION

Mr. FICKETT. Mr. Chairman and members of the committee, my name is Arnold Fickett. I am director of the Advanced Conversion and Storage Department for the Electric Power Research Institute.

With me today is Mr. Joseph Porter of EPRI's electric systems division, who is prepared to respond to questions on electric energy systems.

At EPRI we have long considered our relationships with the Department of Energy's Divisions of Electric Energy Systems and Energy Storage Technology as exemplary. During the past 2 years these relationships have survived a very difficult challenge. I am referring to the major reduction of funding and the substantial shift in emphasis from a near-term application of technology to a longer term basic research. This combination has threatened several joint EPRI/DOE project activities.

However, during these same 2 years we have worked very closely with the DOE staffs and together have facilitated a transfer of many near-term efforts to the private sector, and I would like to enumerate a few of these.

Underground pumped hydro energy storage activity was transferred to the private sector following a series of cost-shared EPRI/DOE projects. EPRI now, along with the potential suppliers, is assuming the complete responsibility for development of improved components for underground pumped hydro.

DOE terminated the storage battery electric energy demonstration project, which would have demonstrated a full-scale, 30 megawatt-hour lead-acid battery in a utility system. EPRI has scaled down this project to 500 kilowatt-hour, and will demonstrate a smaller battery in the battery energy storage test facility, known as BEST, in 1983.

As Mr. Tribble mentioned, DOE is concluding both near-term and long-term compressed air storage technology work. Last month EPRI assumed responsiblity for DOE's sole remaining project in this area, a field evaluation of an aquifer air storage facility in Pittsfield, Ill.

DOE has reduced advanced direct current to alternating current inverter efforts, while EPRI has increased its activities and is pursuing this technology for near-term application.

Electrolytic hydrogen technology, partially developed under DOE contract, is presently being demonstrated at two utility sites through EPRI- and utility-funded projects.

Finally, DOE is reducing its role in low head hydro development, while EPRI—whose involvement is very new—is agreeing to provide an active role in transferring the technology from the small hydro demonstration projects to the private sector. EPRI is also funding efforts to reduce the capital cost, to try to expand the economically viable sites for small hydro.

In accomplishing the above over a very short period of time, the EPRI and DOE staffs have cooperated in every way possible. EPRI has frequently reprogramed its activities, dropping longer range and lower priority work in order to pick up the nearer term efforts. DOE staff has provided excellent support to us during this technology transfer phase.

However, now as we look toward 1984 we are again concerned by the possibility of even further funding reductions that would erode the long-term and supporting R&D that is essential if the private sector is to continue to assume responsibility for near-term efforts. Specific project areas in which continuing DOE support is needed, and we view as essential, are described:

Electric energy systems: Basic and applied research in electric field effects is of major importance to EPRI's Energy Analysis and Environment Division, which is currently spending about $3 million annually to understand the biological impacts of electric fields. DOE has been supporting this effort and should continue to support it at about the EPRI level.

Research on both direct and alternating current power delivery systems should be continued to assure system reliability and improved network stability. Research in dielectric materials, electromagnetic pulse effects, as well as system stability and protective concepts, are very important components of these activities. We especially hope that adequate funds remain available to continue the efforts on system stability and emergency detection control and mitigation. DOE funding of about $10 million in this total power delivery area would seem appropriate, and equivalent to what EPRI is spending in the same area.

Research and development should be continued in systems technology, including multiterminal high voltage direct current systems, advanced underwater cable, superconducting technologies for power system applications, and utility load-leveling. We specifically request that DOE maintain its involvement in the BEST facility for at least one more year. We have tried to secure private funds to replace those provided by DOE. However, the batteries that will be tested in BEST over the next few years are seen as too developmental and too high-risk for appreciable private sector commitment. EPRI's annual budget in this systems technology area is at about $15 million a year. A DOE budget between $10 and $13 million is suggested.

Under energy storage, electrochemical energy storage research and development efforts should continue at their present or slightly increased levels. Advanced batteries, that you heard about earlier—such as sodium-sulfur, zinc-halogen, or redox—continue to show great promise for utility load-leveling and/or electric vehicles. However, they are still at the developmental stage and it will be at least 5 more years before they are ready to be considered for commercial activity and many more years before they are truly commercial. During this time period, the funds required to support these battery activities will increase as larger and larger hardware systems are evaluated. EPRI and other private sector funding in this area is between $15 and $20 million a year. Because of the long-range aspect of many of these activities—I might say most of these activities—we solicit DOE's support at the higher end of this range.

In the physical and chemical energy storage research and development area, efforts should be continued to examine the advanced concepts for hydrogen production, as well as improved materials and designs for use in advanced energy storage concepts such as superconducting magnetic energy storage, flywheels, and thermal storage. EPRI and the private sector will expend between $4 and $5 million annually on the nearer term technology efforts, such as compressed air storage and underground pumped hydro. It would seem appropriate for DOE to provide a similar level of funding for the longer range activities.

Under low head hydro, research and development activities are still required in the environmental impact mitigation area, principally in understanding instream flow requirements. A factual data base is necessary to minimize the delays and costs that are presently being encountered as we try to move forward with many of these small hydro projects. Also, the technology transfer efforts need to be continued, and this is probably a very cost-effective effort because this allows EPRI to become effectively involved. Consideration might also be given to exploring R&D on longer range, lower cost equipment that could expand the number of economically viable applications. EPRI and the private sector are planning to spend between $2 and $3 million on low head hydro in 1984. A corresponding level of support from DOE would be appropriate.

In summary, EPRI is committed to continue our close relationship with DOE, and we will do everything possible to support the nearer term technologies and expedite the commercial use of those technologies. However, we must continue to look to DOE to provide a longer term research base as well as part of the supporting research required to complement the private sector activities. We therefore urge that funding of these important efforts discussed be maintained at adequate levels.

I thank you for the opportunity to make this statement.

[The prepared statement of Mr. Fickett follows:]

STATEMENT OF ARNOLD P. FICKETT
DIRECTOR, ADVANCED CONVERSION AND STORAGE DEPARTMENT
ELECTRIC POWER RESEARCH INSTITUTE
to the
ENERGY RESEARCH AND PRODUCTION SUBCOMMITTEE
OF THE HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
OVERSIGHT HEARING ON
DOE ELECTRIC ENERGY SYSTEMS AND ENERGY STORAGE
Washington, D.C.
March 17, 1983

Madame Chairman and Members of the Committee: My name is Arnold P. Fickett, Director of the Advanced Conversion and Storage Department for the Electric Power Research Institute. On behalf of EPRI, I would like to thank you for the opportunity to appear before this Committee and present our perspective on the need for continuing government sponsored R&D in electric energy systems, energy storage and low head hydro.

Accompanying me is Mr. Joseph Porter of EPRI's Electric Systems Division who is prepared to respond to questions on electrical systems R&D.

The Electric Power Research Institute was established in 1973 to plan and manage a comprehensive research, development and demonstrative program for the entire electric utility industry and its rate payers. EPRI is supported by voluntary contributions from investor-owned, government-owned and cooperatively-owned electric utilities. In 1983, EPRI will expend approximately $300 million on research, development and demonstrations to help ensure an adequate environmentally acceptable supply of economical and reliable electricity.

In general EPRI emphasizes R&D that will result in near and intermediate term benefits. For example, about 70% of the EPRI effort is focused on projects that should provide benefits to the utilities and their customers within the next ten years; while only 5% of the effort is characterized as having a payoff beyond twenty years. We believe that this emphasis nicely complements the federal government's emphasis on the longer-term developments.

At EPRI we have considered our relationships with the Department of Energy's Divisions of Electric Energy Systems and Energy Storage Technology as exemplary. During the past two years, these relationships have survived a difficult test. I am referring to the major change in the Federal R&D role that was accompanied by a significant reduction in funding and a substantial shift in emphasis from a near-term application of technology to longer-term basic research. This combination threatened several joint EPRI-DOE project activities. However, during the past two years we have worked closely with

DOE and together have facilitated the transfer of most near-term efforts to the private sector. For example,

- Underground pumped hydro (UPH) energy storage activity was transferred to the private sector following a series of cost-shared EPRI/DOE projects. EPRI has, along with the potential suppliers, assumed responsibility for the development of improved components for UPH.
- DOE terminated the Storage Battery Electric Energy Demonstration (SBEED) project which would have demonstrated a full scale lead-acid battery in a utility system. EPRI has scaled down this project from 30 MWh to 500 kWh and will demonstrate the smaller battery in the Battery Energy Storage Test (BEST) Facility in 1983.
- DOE is concluding both near-term and long-term compressed air energy storage (CAES). Last month EPRI assumed responsibility for DOE's sole remaining project in this area, a field evaluation of aquifer air storage.
- DOE has reduced advanced dc to ac inverter efforts. EPRI has increased its efforts and is pursuing this technology for near-term applications.
- DOE-developed electrolytic hydrogen technology is presently being demonstrated at two utility sites through EPRI/utility funded projects.
- DOE is reducing its role in low-head hydro development. EPRI, whose involvement in hydro is relatively new, has agreed to provide an active role in technology transfer from the small-hydro demonstration program and is funding efforts to reduce the capital cost of small hydro projects.

In accomplishing the above over a relatively short time period, the EPRI and DOE staffs have cooperated in every way. EPRI has frequently reprogrammed its activities dropping longer range and lower priority work in order to pick up the nearer-term efforts. DOE has provided excellent support during the technology transfer phases.

However, as we look toward 1984, we are concerned by the possibility of even more funding reductions that could further erode the long-term and supporting R&D that is essential if the private sector is to continue to assume responsibility for the near-term efforts.

Specific project areas in which continuing DOE support is needed and viewed as essential are discussed below:

Electric Energy Systems

- Basic and applied research in electric field effects is of major importance to EPRI's Energy Analysis and Environment Division which is spending approximately $3.0 million annually to understand the biological impacts of electric fields. DOE support should continue at this level.

- Research on both direct and alternating current systems should be continued to assure system reliability and improved network stability. Research on dielectric materials, electromagnetic pulse effects, as well as system stability and protective concepts are important components of these efforts. We sincerely hope that adequate funds are available to continue the efforts on system stability and emergency detection control and mitigation. DOE funding at about $10 million would be appropriate and equivalent to EPRI funding in this area.

- Research and development needs to be continued in systems technology including multiterminal high voltage direct current systems; advanced underwater cables; superconducting technologies for power system applications; and utility load leveling. We specifically request that DOE maintain its involvement in the BEST Facility for at least one more year. We have tried to secure private funds to replace those provided by DOE. However, the batteries that will be tested in BEST over the next few years are seen as too developmental and high risk for appreciable private sector commitment. EPRI's annual budget in this "systems technology" area is at about $15 million per year. A DOE budget of $10-13 million is suggested.

Energy Storage

- Electrochemical energy storage research and development efforts should continue at present or slightly increased levels. Advanced batteries (sodium-sulfur, zinc-halogen, redox, etc.) continue to show great promise for utility load leveling and/or electric vehicles. However they are still at the developmental stage and it will require five or more years of R&D support before they can be considered ready for demonstration, and many more years for commercial application. During this time period the funds required to support these battery activities will increase as larger hardware systems are evaluated. EPRI and other private sector funding in this area is between $15-20 million/year. Because of the long-term aspect of many of these activities, we solicit DOE support at the higher end of this range.

- Physical and chemical energy storage research and development efforts should be continued to examine advanced concepts for hydrogen production, and evaluate improved materials and designs for use in energy storage concepts such as superconducting magnetic energy storage (SMES), flywheels, and thermal storage. EPRI and the private sector will expend between $4 and 5 million annually on the nearer-term technologies (compressed air energy storage and pumped hydro). It would seem appropriate for DOE to provide this same level of support for these longer-range activities.

Low Head Hydro

- Research and development activities are required in environmental impact mitigation, principally in instream flow requirements. A factual data base is necessary to minimize the delays and costs that are presently encountered. The technology transfer efforts need to be continued. This is probably the most cost effective activity that can be done in that it is allowing EPRI to become effectively involved. Consideration should be given to exploring R&D on lower cost equipment that could expand the number of economically viable applications. EPRI and the private sector are expending between $2-3 million annually on low head hydro, a corresponding level of support from DOE would be appropriate.

In summary, we are committed to continue our close relationship with DOE and will do our part in supporting the nearer-term technologies and expediting the commercial application of those technologies. However, we will continue to look toward DOE to provide the long-term R&D base as well as part of the supporting research required to compliment the private sector activities. We therefore urge that funding of these important efforts discussed above be maintained at adequate levels.

Thank you for the opportunity to present this statement.

ARNOLD FICKETT

Arnold Fickett is the Director of the Advanced Conversion and Storage Department, Energy Management and Utilization Division, at the Electric Power Research Institute (EPRI) in Palo Alto, California. He joined the Institute in 1974 as a Project Manager in the Fuel Cells Program and was promoted to Manager of the Fuel Cell and Chemical Energy Conversion Program in 1976.

Prior to joining EPRI, Fickett had been with General Electric Company from 1956 to 1974. From 1970 to 1974, he was Manager of the Direct Energy Conversion Program's Engineering Section. He has over twenty years of experience in the research, engineering and application of electrochemical technologies.

Fickett received a B.S. degree in Chemistry from Bates COllege, Lewiston, Maine, in 1956 and a M.S. degree in Electrochemistry from Northeastern University in 1965.

A member of the American Chemical Society and the Electric Chemical Society, Fickett is the author of numerous publications and holds several patents in the field of fuel cells and direct energy conversion.

July, 1981

Mr. VALENTINE. Thank you very much, sir.

Unless you gentlemen have some objection, we will let them all speak.

Mr. Fink, we are happy to have you here. If you are ready, sir, as far as we are concerned, you may summarize your statement or however you care to proceed.

STATEMENT OF LESTER H. FINK, PRESIDENT, SYSTEMS ENGINEERING FOR POWER, INC., ON BEHALF OF THE RESEARCH AND DEVELOPMENT AND ENERGY COMMITTEES OF THE INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS, INC.

Mr. FINK. Thank you, Mr. Chairman.

I will try to summarize my statement as briefly and succinctly as possible.

I am representing the Institute of Electrical and Electronics Engineers, and I am speaking in particular with regard to one aspect of the electric energy systems division program which is most often overlooked. I find this somewhat ironic because we have become accustomed over the past several years to hearing repeatedly that the mission of the Government in research is to support longer range research, and quite often the adjective high risk is appended to that description.

The one element of the electric energy systems program which ideally fits the description of the type of research that the Government should be supporting is that which is most often overlooked. I am speaking specifically about the research in the area of systems theoretic developments.

This element of the program is definitely longer range, generic, applied research. It is addressing problems that are unaddressed by other segments of the research community. It has proven effective over the past 8 years with regard to the early preliminary results, which have already found application throughout the industry. Yet when we look at the proposed fiscal year 1984 budget, it is conspicuous by its absence.

The electric energy systems program, I submit, is the only long-range applied research program which is addressing generic problems emerging from the radically changing characteristics of the Nation's electric energy systems. These characteristics involve emergence of new technologies, the emergence of new systems structures, and the emergence of new, restrictive financial, physical, and operating constraints. They are posing problems of a fundamental nature to the operation and continued viability of the Nation's electric energy systems.

In order to insure continued efficient, effective, and reliable service, these characteristics require development of a new body of applied systems theory. Power system research traditionally has been carried out primarily by equipment manufacturers, and the manufacturers were concerned, properly, with product improvement and product development. Such research, being component oriented, never did really address problems in effective systems structuring and performance.

The Nation's electric energy systems, which are uniquely reliable and effective in their operation compared to systems elsewhere in the world, have evolved slowly over a century, and they have done so very effectively, but they have been based primarily on theoretic work which was done in the 19th and 18th centuries. Now when we are entering a period when some of their basic characteristics are changing drastically and rapidly, there is no viable available body of theory to provide sufficient guidance as to how the restructuring and operation of the systems under these new conditions should be conducted.

The research program of the Electric Power Research Institute, as you have heard, is perforce increasingly addressed toward nearer term problems that are very important to the industry but require rapid, effective responses.

If we turn and look at the record of the program of the electric energy systems group within the Department of Energy, most of those results which have already been adopted by the industry turn out to be those which have developed from the generic, longer range, systems theoretic work of the type to which I am alluding. The program, and particularly this aspect of the program, has achieved worldwide recognition. I have seen repeated reference to this work in many of the European nations, in the Far East—in Japan in particular—and even in Australia.

Yet, as I said earlier, the 1984 budget is deficient in two respects. First of all, it has almost eliminated funding for these aspects of the program. Second, the proposed 1984 budget slashes the staff of this group by 83 percent, providing support for perhaps two professionals, which is totally inadequate to develop and maintain a program of this nature.

Let me give a couple of examples of the type of work to which I am alluding. In the area of operation of our electric energy systems, one important aspect is the ongoing evaluation of the potential vulnerability of the system in real time to potential disturbances which may take place, and to make sure that the stance of the system is robust enough to ride out any such potential disturbances.

The current methodologies for doing this, as they have evolved over time, have been very pragmatic. When the systems were smaller and the problems were less complex they were very effective. The approach was to look at a long list of possible disturbances and to see if the system would indeed respond reliably under such disturbances.

However, when we start to consider systems consisting of 1,000 or 1,500 buses, of multiple thousand transmission lines, and lists of potential disturbances perhaps reaching 10,000 at the simplest, we realize that it is unrealistic in real time, continually, every few minutes, to look at the potential response of the system to all of those possible disturbances. There is a very real need for development of techniques, methodologies, which will enable system operators to assess the robustness of their system in the face of potential disturbances without looking in detail at the tens of thousands of possible disturbances that might be considered. This is work of a generic, long-range nature, which needs doing, which no one else is addressing, and which is entirely appropriate to a program such as this funded by the U.S. Government.

I can mention several other examples but in consideration of time, I will not. I will just conclude by reemphasizing that the electric energy systems program is unique in its emphasis on longer range generic problems; that these problems are not and are not likely to be addressed by the private sector for a variety of reasons; that the program has proven effective in past years by virtue of the early results which have been picked up and adopted by industry; and that as the fiscal year 1984 budget is presently structured, this program cannot survive, both by virtue of lack of funding and by virtue of lack of staff support to support the program generally.

I thank you very much for this opportunity to present these reflections to you.

[The prepared statement of Mr. Fink follows:]

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Statement on Electric Energy Systems

by Lester H. Fink
on behalf of the
Research and Development and
Energy Committees of the
Institute of Electrical and Electronic Engineers, Inc.

Delivered before the Subcommittee
on Energy Research and Production
House Science and Technology Committee

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March 17, 1983

Mr. Chairman, Members of the Subcommittee, my name is Lester H. Fink, and I appear before you today on behalf of the Energy and Research and Development Committees of the Institute of Electrical and Electronics Engineers, Inc. (IEEE). The IEEE is the world's largest technical professional society, with over 215,000 members worldwide, more than 165,000 of whom live and work in the United States.

The IEEE has an official Institute position paper on Electricity in the United States which emphasizes the fundamental importance of energy availability to the welfare and economic health of society, which recommends an increased role for electricity in the nation's energy economy, and which calls for increased support of research and development programs to improve electric power system efficiency and reliability, as well as advanced energy conversion technologies.

The IEEE has consistently supported the Electric Energy Systems program in testimony before Congressional committees having oversight over its budget. We strongly support continuation of that program.

The Electric Energy systems program is one which, at a modest level of funding, has achieved significant results. Continuing elements of the program meet the announced criteria for government support: long-range, high risk research un-likely to be funded by the private sector. Lack of private sector support occurs not only because of current severe shortages of funds for any needs beyond current critical operating needs, but also because the ultimate benefits will accrue to the industry and the economy at large, with only modest shares to any corporate entity within the industry. The program's major benefits are in the realm of advances in the basic theory of electric energy systems, which will be required for the effective understanding, design, and operation of the complex new structures and functions which are evolving, and in the recruitment and training of young professionals at the post graduate level. The program's achievements to date, documented in the open literature, have already had a significant impact on electric energy systems-related research and even, in some cases, practice, while young professionals who participated in graduate research under the program are already beginning to inject new vigor into university power engineering programs as well as the power industry at large.

JUSTIFICATION FOR GOVERNMENT SUPPORT

In supporting the Electric Energy Systems program, it is appropriate first to speak to the need for active support by the federal government, and what its role should be. The appropriateness of an active federal role follows from the facts (I) that the product of the industry involved is crucial to the economic well-being and security of the nation, (II) that the problems involved are basic in nature with serious long-range consequences if they are not resolved, and also are generic in nature with benefits of their solution accruing to the industry at-large and the national economy, and (III) that support for such a research program by the private sector is precluded by a variety of factors.

Let me speak to each of these three issues. The first point will elicit little if any disagreement, so will need little buttressing. Over the past century, modern western economies, including most notably that of this country, have evolved with electric energy serving as the life-blood. Electricity provides 20% of the energy used in industrial, commerical, and domestic applications in the United States, and that fraction is growing. For the most part, no practicable substitute energy source exists. Without a reliable supply of electric energy, our technological economy and our standard of living would retrogress, and our national security would undergo horrible cost escalation, insidious degradation, or both.

The second point is less obvious, but no less important. It is that the evolution of our nation's electric energy systems have carried them to a stage where, as very large-scale, complex systems, they are facing problems different in kind from those with which they have dealt in the past.

Electric energy technology is the outgrowth, and flowering, of scientific discoveries made in the late eighteenth and early nineteenth centuries. Much of the basic electric science was encompassed and codified in the masterful work of James Clerk Maxwell, embodied in an epochal pair of volumes entitled "A Treatise on Electricity and Magnetism" which appeared in 1873. Electric power engineering education is still based solidly on the electromagnetic field equations of Maxweell and on the derivative circuit equations of his contemporary Gustav Kirchhoff. It is not that there have been no advances in electrical science in the last century. Rather, the basic science on which our modern electric technology rests is based solidly on evolutionary developments from its nineteenth century foundation. Today, however, the evolutionary development of electric energy systems has carried them to a stage where, by virture of increasing dimensionality and increasing complexity, major new problems are emerging which are different in kind from the familiar ones of the past, and which are no longer contained even seminally in the works of Maxwell and his successors.

The problems involved are those dealing with the understanding of very large systems. They include both the analysis and the synthesis of such systems. They can be treated effectively only by the emergent discipline of systems science and engineering, which is just beginning to take shape. The ability of such a new discipline to deal effectively with problems as fundamental, far-reaching, and complex as those with which we are concerned will depend on the extent to which that discipline is nurtured by research carefully conceived and guided.

Support by private industry for research of the type under discussion is precluded by a number of factors. With the exception of the few utilities widely recognized as having a meaningful research program, most utility industry research has been conducted by manufacturers. Manufacturers generally have not supported long-range speculative research, which yields no immediate payback or profit: Most require a return on their research investments within five years or less. Tax structures, foreign government-supported competition, and the growing cost-price squeeze all tend to limit manufacturer research support; such as does exist is directed toward improvement of existing lines of equipment in which they have a heavy investment. Internally supported research on new technologies, or on system-related, as contrasted with component-based, problems, is virtually non-existent. Utilities' support of research is limited not only by their current financial strait, which is increasingly severe in some regions of the country, but also by regulation and local rate based pressures, and is generally limited to solution of their own immediate problems or support of EPRI. EPRI itself is being forced by regulatory pressures on its member utilities to place increasing emphasis on the solution of near-term problems. Almost since its inception, it has emphasized two major current issues, the increased use of coal and uranium, which have received a dominant and increasing share of its budget.

Research of the type under discussion clearly qualifies for government support. It is:

- Crucial to the national well being
- Basic and generic in nature, with long-term benefits accruing to not only to the utility industry at large, but to other sectors concerned with large scale systems

- o Research which the utility industry itself is precluded from conducting by a variety of factors.

These characteristics of the Electric Energy Systems Research program are clearly consistent with the Administration's criteria for Federal support.

CHARACTERIZATION OF THE ELECTRIC ENERGY SYSTEMS PROGRAM

The Electric Energy Systems program was established within the Department of Interior in med-1974 as a research program to address the longer range technical problems of the nation's electric power systems, as systems.

From its inception, it has attempted to take a broadly based, long-range view of electric energy systems technology and its research needs, and to direct its efforts toward development and support of research capabilities and efforts in crucial problem areas unlikely to be widely recognized or supported by private industry. Major foci of the program, subsidiary to this objective, included basic systems engineering theory and applications relevant to perceived electric energy systems needs, high voltage bulk power transmission technology for both alternating current and direct current, and initially also low voltage power distribution technology, an element of the program which has since been phased out.

By virtue of the manner in which it was originally conceived, the program has been unique in fundamental respects. This testimony seeks to explain and emphasize its unique characteristics, since they further justify the program's claims to government support, and since if it were discontinued there would be no program left supporting work of a comparable nature.

During initial formulation of the Electric Energy Systems program, it was realized that deepened understanding of the basic characteristics of electric energy systems, at an abstract mathematical level, would provide a uniquely powerful basis for attacking and resolving problems of the widest variety, whenever they were identified and their importance became apparent. This early premise of the program has been repeatedly substantiated as, repeatedly since then, even preliminary and fragmentary results have yielded unique practical insights into diverse practical problems. It must be emphasized that these benefits relative to specific problems have resulted from resesarch directed, not at those problems, but only at strengthening our basic understanding of systems at the abstract level. It is just because of the fundamental nature of the work that it has been so widely useful.

Thus, the Electric Energy Systems research program has been unique, first, in its focus, taking a purposeful, cooordinated approach to pursuing answers to the long-range fundamental technical problems of the electric energy industry as a functioning interacting system. This is an important point which I cannot stress strongly enough. Disparate technologies cannot be independently developed, manufactured and connected into this vast complex, even fragile, system, without fundamental scientific understanding of the subtle systems relationships and interactions which govern the overall functioning of the system and determine its viability, to say nothing of its reliability. In this respect, the Electric Energy Systems program, with its focus on the emergent systems-related problems of the nation's power systems, and its exploitation of the new discipline of systems engineering, has been making a unique contribution to the nation's research effort and to the long-range resolution of fundamental problems important to the health of our economy.

The Electric Energy Systems research program has been unique also in its modus operandi, by virtue of the manner in which research projects are defined and chosen for support. Sponsorship of research can be a delicate matter. Deep results yielding significant advances in understanding almost always are achieved only by investigators intellectually captivated by the problems on which they are working, and who are free at each stage of their investigation to pursue the next step toward their problem. This is why the National Science Foundation has been so successful with its program of support for unsolicited proposals. Their role lies not in the choice of research topics, but rather in evaluation of topics which would-be investigators see as challenging and promising. This permissive approach, culling out and supporting the best projects to which individual investigators are most committed, meets a necessary condition for fruitful research--that the investigator be geniunely and deeply interested in his problem. Productive research requires the bringing to bear on a problem of all relevant (and sometimes apparently irrelevant) experience and knowledge of the investigator, focused on the problem through the lens of his interest, to kindle a spark of new insight which can then be nursed into a flame of new knowledge.

The Electric Energy Systems program has taken a modified approach, neither permissive nor mandatory, and its success has been widely recognized. Its approach has been to devote attention first to identifying important generic problems affecting the nation's electric energy systems, especially emergent problems not yet widely recognized, and then, not specifying research to be conducted on those problems, but rather defining their basic features in terms which are both understandable and challenging to investigators in relevant academic disciplines who might normally have been uninvolved in power system problems. Having provided such definitions of important emergent problems, the program has invited proposals for research on contributions to the resolution of facets of those problems. This has resulted in the funding of groups of projects by investigators in a variety of disciplines, each contributing uniquely and in a complementary fashion to a closely related set of subproblems, each of which in turn was of genuine interest to its investigator.

It is important to note, and this is critical to the strength of the program, that although any one of such projects might in itself be speculative and high-risk, there is a good probability that, taken collectively, some one or more of that group of projects will yield valuable results. Over the past several years, the strength of this strategy has been demonstrated repeatedly. Moreover, because we are dealing with concepts, not with hardware, the cost of pursuing such a strategy is modest.

There are difficulties in such an approach. First, it requires that the program personnel have an unusually deep and mature technical understanding of electric energy systems, of their technical nature, their technical characteristics, their technical evolution, their current and above all their emergent technical problems. Second, it requires that these same personnel have an awareness and appreciation of, and a reasonable ability to speak the language of, a wide range of academic engineering and scientific disciplines which might have contributions to make toward the solution of such problems. Third, it requires that these personnel be able to suppress their personal biases with regard to likely approaches to solutions: the more slanted a problem statement is toward a particular approach to a solution, the less likely it is to stimulate the interest of someone who might contribute a more powerful alternative approach.

I might point out here that the assembling of a staff having such qualifications was quite an achievement, and maintaining its nucleus is important.

The FY '84 budget request now in question, while it provides funding for the EES program at a level of 12.7 M., is seriously deficient in several respects. In effect, it constitutes a massive departure from the basic historic objectives of the program as I have attempted to outline them in this testimony. In line with the continued attrition which the program has been undergoing over the past several years, with few exceptions those elements in the FY '83 budget which were most supportive of the program's basic rationale and objectives have not been included in the FY '84 request. In particular, I refer to the work on emergency detection and control, on reliability evaluation, on advanced materials research, on system efficiency, and on communications, control and operations, which were funded collectively at 6.4 M in FY '83 and which require continued funding at about 8 M in FY '84.

It should also be noted that the FY '82 and FY '83 budgets included specific provisions by the Congress for work on development of a deep water submarine cable, and that continuation of this development into FY '84 will require funding at a level of 4.8 M, whereas the budget request includes only 1.0 M for this item. For a program of the size of EES, such a difference cannot be repaired by diverting funds from other program elements, especially when, as already noted, the very core of the program, from which its continued viability depends, is already seriously underfunded. Should the Congress wish to continue this element of the program, adequate funding should be provided explicitly.

Finally, and most seriously, I have already emphasized the impossibility of supporting such a program without an adequate staff having rare technical and professional capabilities. The FY '84 budget request slashes program direction by nearly 80%, from 0.5 M in Fy '83 to 0.102 M in Fy '84. If this request is not amended at this point to provide for retaining the staff at the minimal level to which it had been reduced by FY '83, the program to which I have been speaking will be dead, regardless of any ostensible funding under the heading of EES.

A research program with as broad a field of responsibility as has the Electric Energy Systems program is really out-of-place in any agency subdivision whose responsibilities are narrowly defined. From the time it was transferred from the Dept. of Interior into the new Energy Research and Development Administration, it has been placed in non-research oriented portions of its agency, to which its charter and concerns were related only peripherally at best. Because of its broadly based, fundamental nature, it has naturally contributed support to all of these areas, but to none of them exclusively, so that it has always seemed to be misplaced and ill-fitted in any of these agency elements, recurrently being forced to show cause to its own management why it should exist, and surviving only through the strong support of the Congress. It is suggested that its proper mission can only be pursued effectively, with full understanding and support of its management, if it be included in a broadly based element such as, for instance, the Office of Energy Research.

CONCLUSIONS

This testimony has described to you a specific research program which, at modest level of funding, with little support, has been making a significant contribution of the long-range technological needs of one the nations most vital industries. This program is unique in its focus on fundamental long-range problems of a pervasively systems-related nature, and in its emphasis on powerful generic and wholistic, rather than ad hoc, solutions. It is unique also in its manner of defining research objectives so as to enlist the dedicated involvement of leading research investigations from a wide-range of systems-related backgrounds. Despite its avowedly long-range focus, the program has already demonstrated its value by virtue of interim results that are already finding use

If any research program qualifies for support by the Federal government, the one which has been described clearly does so. Yet this program has been successively reduced, year by year, since about 1978, and now faces extinction.

We urge the Congress to restore funding for the Electric Energy Systems program at a level which will enable it to sustain its uniquely formulated and thus far unusually successful research effort, to take immediate action to relocate it under an agency element having a charter accordant with and supportive of these broadly-based, long-range research concerns, and to look to assurance of qualified staff at an adequate level.

I thank you sincerely for this opportunity to bring you this testimony.

Mr. VALENTINE. Thank you very much, Mr. Fink.

Mr. Helfrecht, who is accompanied by Mr. Roger Boom, I believe.

Mr. HELFRECHT. That is correct.

Mr. VALENTINE. We will be happy to hear from you at this time, sir.

STATEMENT OF DONALD J. HELFRECHT, PRESIDENT, MADISON GAS & ELECTRIC CO., AND PRESIDENT, WISCONSIN ELECTRIC UTILITIES RESEARCH FOUNDATION, ACCOMPANIED BY ROGER W. BOOM, PROFESSOR OF NUCLEAR AND METALLURGICAL ENGINEERING, UNIVERSITY OF WISCONSIN

Mr. HELFRECHT. Thank you, Mr. Chairman.

As you indicated, I am Don Helfrecht, the president of Madison Gas & Electric Co., based at Madison, Wis. I also happen to be the president of the Wisconsin Electric Utilities Research Foundation, whose members are the five investor-owned electric utilities that serve the State of Wisconsin and who do support research and development activities on an individual company basis, as members of the Electric Power Research Institute, and through our own Wisconsin foundation.

With me here this morning is Prof. Roger Boom of the Department of Nuclear Engineering at the University of Wisconsin at Madison. Dr. Boom is the project manager for the superconductive magnetic energy storage project at the university. He is right here, sir.

We have both submitted written testimony for your permanent record, Mr. Chairman. I would like to comment briefly further, however.

Our utility foundation in Wisconsin has provided $1.5 million of the $6.5 million which has been invested to date in the Wisconsin SMES research, as it is referred to. The remaining $5 million has been provided by other organizations, primarily the General Electric Co., the National Science Foundation, and the Department of Energy, as well as the University of Wisconsin.

Superconductive magnetic energy storage, as conceived at Wisconsin, is a highly efficient energy storage system which takes advantage of the characteristic of certain metals in an extremely low-temperature liquid helium environment of 1.8° K to conduct an electric current with zero resistive loss. A second primary advantage is the fact that SMES takes energy as alternating current, converts it to and stores it as direct current, and returns it to the interconnected network as alternating current by converting that stored direct current, using the same rectification system that placed it in storage in the first place.

This is done in a daily or diurnal cycle. That is, the large, direct current magnet is charged during the nighttime hours using low-cost, off-peak generated power. That stored energy, then, is returned to the utility network during the daily peak period, replacing either peaking power or intermediate load range cycling power.

Only superconductive magnetic energy storage stores energy without changing it to some other form of energy, namely, chemical, mechanical, or kinetic. For this reason, superconductive magnetic energy storage is 15 to 30 percent more efficient than all other types of presently known storage.

Superconductive magnetic energy storage has several unique advantages over other forms of storage. First of all, its round trip efficiency is in excess of 90 percent. It has a very high availability of 95 percent. It is forecasted, once developed, to have a very long life of 50 years because it is basically a quiescent device, other than the charging of current during the nighttime and the removal of current during the daytime.

It can replace our current generating equipment which is referred to as intermediate range equipment. Basically that type of equipment would return to what it was originally built as, baseload equipment. One other very critical factor in SMES is that it has rapid power reversal characteristics. It can reverse from a charging characteristic to a discharging characteristic in under 33 milliseconds, and thereby respond to system stability and system emergency conditions.

It can be used, similar to other storage facilities, for spinning reserve. As I indicated, it lends stability to the utility system. It can be used as a device to control the regulation on the operation of the utilities generating equipment.

A very significant characteristic is its ability to store large quantities of energy required in our utility grid to match the large swings between the daily minimums and maximums on the systems, thereby leveling out the load on the generators which are producing the original electric energy. It also can be used to store other forms of generated electricity, such as solar, wind, photovoltaic energy produced at the time that they can be produced, and then through the use of this device returned to the interconnected system when there is a specific demand for it.

Our electric utility industry has only a very few forms of storage available to it. These, namely, are pumped hydro, underground pumped hydro, compressed air, advanced compressed air, or batteries. Many millions of dollars have been invested in the development of these technologies. Our industry needs all forms of efficient, economic storage. At the present time millions of dollars have been spent on batteries and hydro. As Mr. Fickett indicated previously, we do not have as yet an operating battery storage system.

SMES is the most efficient but newest, least known, and least funded to this date, of this type of storage technology. Research and development needed to prove the superconductive magnetic energy storage technology is small compared to other national storage program efforts. A 4-year, $15 million program has been proposed. This program would complete the following items:

It would go into the component research and development of the conductive material which has been designed at the University of Wisconsin. It would complete investigation of the structural capabilities and type of struts to be used, the development of the helium container which provides the low temperature in which this magnet operates. There are things that have to be designed yet with respect to the excavation of the trench that is necessary and, of course, the fabrication of the conductor itself in a field environment requires further work.

It is proposed that a small storage magnet coil of 10-kilowatt-hour capacity be designed in the first 3 years of this 4-year program; that it would be constructed and tested; and then in the fourth year that investigation of design and test would be analyzed and a decision would be made at that time whether to proceed with a pilot plant.

As a consequence of that development, a design of an optimized 100-megawatt-hour unit up to the potential of 10,000 megawatt-hour of storage capability would be investigated. Following that, of course, the detailed conceptual design of a full capacity unit could in fact be developed and actual, final costs developed for the construction of such a unit.

This effort, then, would lead to a decision either to construct and test a 100-megawatt-hour demonstration storage unit, or if it does not, obviously the project would have to be dropped at that point with that minimal investment of the $15 million that we are talking about.

A current, independent assessment of the Wisconsin low aspect ratio SMES design which is being conducted for EPRI by Bechtel and General Atomic justifies proceeding with this Wisconsin SMES research. Bechtel's preliminary findings are that the 1,000-megawatt SMES unit which they studied could be only one-half the cost of a cycling coal unit on a per kilowatt basis, after predictable research work has in fact been completed. As I mentioned earlier, the high efficiency of SMES makes coal unit replacement possible.

Now you may ask why Wisconsin is interested and why we support SMES rather than other known forms of storage. Mr. Chandler mentioned the Northwest. The topography of Wisconsin is relatively flat. As a matter of fact, Wisconsin is one of the leaders in the development of hydro in the country. Our Wisconsin rivers have been developed for hydropower to their maximum capability.

Our total installed hydro capacity in the entire State is less than 1,000 megawatts, in a State where our total electrical demand is approximately 6,000 megawatts, and with the variability of the flow of the river obviously it cannot furnish a significant amount of energy over the current year's time. At the present time, the maximum, if we have good flow on the rivers, we may get from 3 to 4 percent of our electrical energy requirements from hydro.

There is minimal opportunity for the development of additional hydro in Wisconsin. There may be a few sites. These have been investigated, and we believe that they would not be developed because of environmental constraints on developing a storage pond.

As far as batteries are concerned, we have yet to see. We of course understand what work has been done in the past. Our own utility experience is that as a matter of actual fact we have lots of batteries on our systems, in all of our substation control buildings, and we are limited to a 10-year life. In my experience I have replaced lots of control batteries. In my utility, at least, I am not about to make an investment in a device that has a limited life of only 5 or 10 years, when it would have to be completely replaced.

Gentlemen, we are here to request that Congress consider direct funding of Wisconsin's superconductive magnetic energy storage research effort. The fiscal year 1983 funding of $2.9 million was appropriated by Congress in the Senate's continuing resolution, and which DOE refused to pay, plus our proposed fiscal year 1984 funding in the amount of $4.3 million pursuant to the Wisconsin proposal, we respectfully request your very serious consideration.

I thank you for this opportunity to address you this morning. Dr. Boom and I would be happy to respond to any questions you might have with respect to this effort.

[The prepared statements of Dr. Helfrecht and Dr. Boom follow:]

Statement of D. J. Helfrecht
President, Madison Gas and Electric Co.
President, Wisconsin Electric Utilities Research Foundation
Madison, Wisconsin

on

Diurnal Superconductive Energy Storage

before the

House Committee on Science and Technology
Subcommittee on Energy Research and Production

March 17, 1983

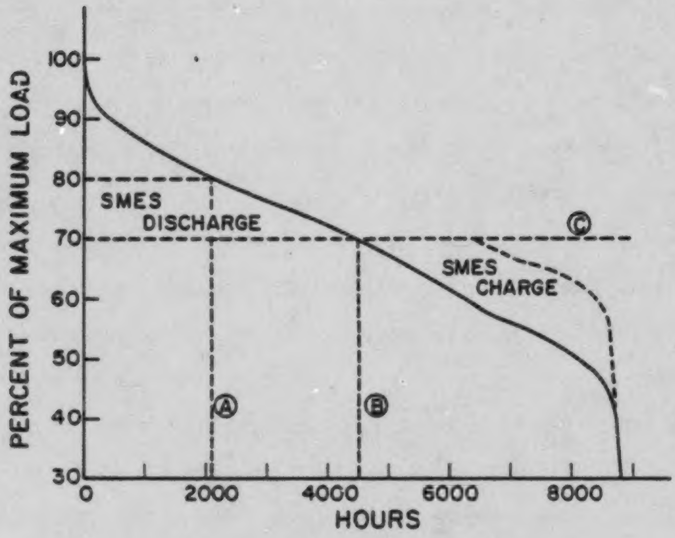
The Wisconsin Utilities are pleased to present this testimony in support of Superconductive Magnetic Energy Storage. As President of the Wisconsin Electric Utilities Research Foundation, I represent all five investor owned electric utilities in Wisconsin:

- Wisconsin Electric Power Company, Milwaukee
- Wisconsin Public Service Corporation, Green Bay
- Wisconsin Power and Light Company, Madison
- Northern States Power Company of Wisconsin, Eau Claire
- Madison Gas and Electric Company. .

I am the third Wisconsin utility representative to testify before this committee. My message is the same as those who have preceded me: Superconductive Magnetic Energy Storage (SMES) has the possibility of becoming the most important new technology in the utility industry in the last quarter of this century. We see SMES as an economic replacement for intermediate load range (ILR) cycling coal generation, thereby in principle eliminating the need for intermediate generator additions and thus using only efficient base load generators. We believe SMES has two distinct advantages: it conserves our energy resources and it uses less expensive power in its storage technology. Energy and costs are saved because SMES is charged at night by base load generators which run steadily without the extra start-up and load following inefficiencies of the intermittent intermediate generators. A base load coal generator might provide night-time energy at 9500 BTU per electrical kilowatt hour (kWh) through SMES while an on-off cycling coal unit delivers daytime energy at about 10,500 BTU/kWh. More energy is required for the cycling unit because of the standby and load following inefficiencies associated with cycling units.

SMES is the only storage type with this energy saving potential because it is 95% efficient for energy pass-through while Batteries, Compressed Air Storage and Underground Pumped Hydro Storage are all in the 60-70% efficient range. Batteries, for example, probably need, 12,700 BTU input for one kilowatt hour output of electricity because the battery system loses about 33% of the input energy. The same losses hold for all other storage types, except SMES.

The use of SMES is sketched on a 1995 load duration curve in Figure 1. Line C, the average load, is 3076 MW. Line A, the minimum time (2100 h) a cycling coal unit might run per year, intersects at 80% of the maximum load ordinate. Line B at 4500 h corresponds to 70% maximum power which is the yearly average. Thus SMES typically discharges from 70 to 80% load and charges from base load coal generation. Since coal generators may have about 70% availability the charge area is sketched from 6130 h (70% of 1 year) to 8760 h (1 year).



1995 WISCONSIN ELECTRIC SYSTEM LOAD DURATION CURVE

Figure 1

I have mentioned the comparison between base load coal plus superconductive storage vs. base load coal plus cycling coal. This is the most important comparison. New oil or gas fired units are presently forbidden by the Fuel Use Act of 1978 for more than 1500 hours per year. (Superconductive Storage can be used 4500 hours per year). All utilities wish to eliminate or minimize oil use and, as a matter of principle, are not ordering any new oil generation.

I see the next 25 years as a period when replacement and expansion generation will be new base load coal units and new intermediate load cycling coal units, with no other choices. The only foreseeable option is storage. Superconductive storage, which is not yet developed, is the most efficient known technology for this purpose.

That brings me to the point of this testimony. We need the support of the Congress to develop this technology. DOE, EPRI and others have invested millions of dollars in battery, underground pumped hydro and compressed air storage research. The Wisconsin Utilities are now the sole supporter of diurnal SMES research and development in the U.S. Our Wisconsin group has limited funding abilities. Up to this point in time, EPRI has viewed research in this area as a long range research project. We believe milestones have been and can be established for significant cost reductions in this technology. We believe SMES, as a storage technology, has national if not international significance and should receive support and funding on a national level.

Mr. Tribble of the DOE testified before the House Appropriations Committee on March 3, 1983 that the major DOE storage program recommendation for FY-84 is battery storage. Mr. Tribble also testified that none of the required breakthroughs have been made for batteries, probably as to battery lifetime and deep discharge capability.

We contend that SMES itself is a major breakthrough. We clearly see the eventual possibility of the intermediate load in the U.S. being provided through SMES, as explained above. Today intermediate capacity is about 15% of the total power capacity in Wisconsin, or about 1000 MW. The total U.S. needs are about 50 times larger, since the state of Wisconsin is about average, or possibly 50,000 MW.

We request support for a 15 million dollar - four year directed program to build a small storage coil and to finish the R and D which has been underway at Wisconsin for the past 10 years. We have spent 6.5 million dollars to date and have received very encouraging confirmation from three independent assessments: one by Arthur D. Little for DOE in 1979, a second by Arthur D. Little for a typical oil burning utility and a third recent assessment by EPRI-Bechtel-General Atomic Company. The potential for the enormous usage mentioned above is confirmed by these assessments.

Adequate cost estimates need to be confirmed by the future research and development of the SMES components. Fifteen million dollars is a modest program in comparison to potential benefits.

Written testimony by R. W. Boom, project manager, describes the necessary research to be completed in the four year period. We strongly urge you to endorse four years of SMES research.

Support on a national level is extremely important to the continuation of the good relationship and technological exchange Wisconsin has established with the Japan. We have received strong indications that extensive collaboration with Japan is possible if we get specific support from our government.

STATEMENT OF R. W. BOOM, PROFESSOR OF NUCLEAR AND METALLURGICAL ENGINEERING UNIVERSITY OF WISCONSIN MADISON, WISCONSIN

on

Diurnal Superconductive Energy Storage

before the

HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
Subcommittee on Energy Research and Production

March 17, 1983

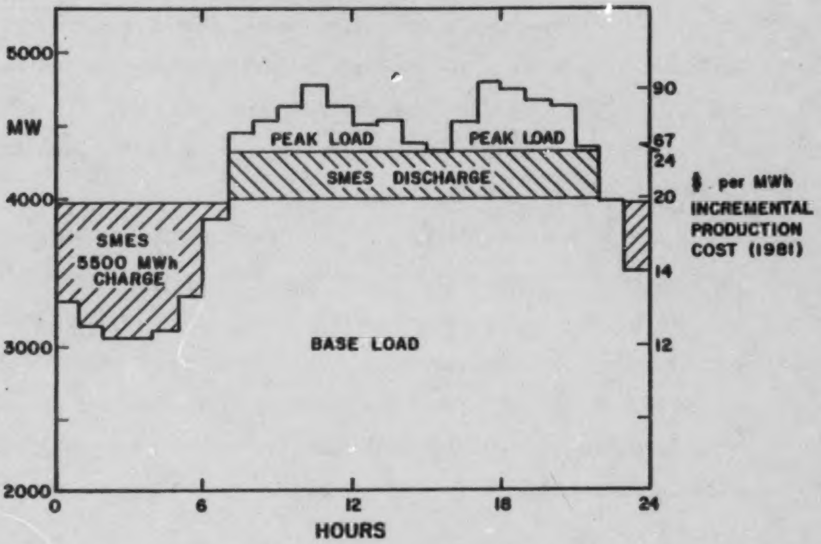
In 1979 and 1980, we appeared before this committee to request that our Wisconsin Superconductive Magnetic Energy Storage (SMES) project be recognized as potentially important to the Nation's electric utility industries. That position has been confirmed by the recent achievement of several highly significant technological and evaluative milestones. These will be discussed in detail later in the testimony. Today we appear before you to request that D.O.E. funding be authorized so that a 100 MWh diurnal SMES prototype unit can be built and tested by 1991.

SMES is the system for the storage of night-time inexpensive electric energy from base load generators to be discharged the next day during high demand periods. Figure 1 is a Wisconsin Electric Power Company load curve plotted as MW power vs. hour of the day for a typical day in 1995. With SMES the base load is a constant 4000 MW and only the small peak load would be met with traditional peaking units. SMES is 95% efficient and discharges 5225 MWh at a constant 373 MW for 14 hours. The traditional competitor for the 14 hour 373 MW discharge is a cycling coal unit which today costs about 1370 $/kW with

Figure 1

WISCONSIN ELECTRIC POWER COMPANY

1995 LOAD CURVE



scrubbers. The cycling coal unit has a higher incremental production cost (22 $/MWh right side axis) than the incremental production cost of charging SMES (14 $/MWh). Adding this production cost advantage for SMES averaged over 50 years and the avoidance cost of coal units which would not be purchased provides a benchmark value for the SMES alternate.

Recent 1983 cost estimates by the Bechtel Corporation and General Atomic Company for an EPRI assessment of SMES show that SMES could cost much less than cycling coal after SMES development is completed.

The specific cost estimates in the final draft report by Bechtel-General Atomic-EPRI for a 5000 MWh unit with 1000 MW power capacity range from $1330 million to $736 million. The upper cost is a present day state of the art estimate and the lower cost is the estimate after ongoing research and development is completed. In comparison, a 1000 MW cycling coal unit would cost $1370 million, which is considerably more than the final estimated cost of SMES. Thus the 1983 Bechtel study for EPRI is a resounding confirmation for SMES.

In 1979 an assessment by the A. D. Little Company for the Department of Energy (D.O.E.) concluded that "SMES can be used by Utilities which cannot economically use any other type of storage system", D.O.E. report C-82820, November 1979. Another statement by A. D. Little is made to the effect that only SMES of all storage types is useful for over 3000 hours per year which almost satisfies the definition in the Fuel Use Act for a baseload plant. The Wisconsin example above is for 14 hours per day for 260 days per year or 3640 hours per year.

Bechtel, A. D. Little and U.W. studies all combine together to support the following unique benefits for SMES.

- 95% storage efficiency
- 95% availability
- 50 year lifetime
- intermediate generator replacement
- rapid power reversal (33 milliseconds)
- spinning reserve

- system stability
- system regulation.

Superconductive magnetic energy storage increases the energy efficiency of an electric utility company, because the less efficient cycling intermediate load and cycling peaking load generators are replaced. Only SMES is efficient enough for such large usage which might typically be 3000 hours to 4500 hours per year. The storage efficiency of SMES is 93% to 95%, depending on design details. Most other new storage; Batteries, Compressed Air and Underground Pumped Hydro would probably not be used more than 1500 hours per year because their efficiences are about 60% to 70%.

The research and development work at Wisconsin has lead to the Low Aspect Ratio storage solenoid which is being assessed by Bechtel and General Atomic for EPRI. The low aspect ratio solenoid is a relatively simple 112 turn solenoid mounted in a shallow surface trench in competent rock or reinforced overburden. This new design has lead to many improved simplifications in the conductor, magnet container, maintenance procedures and construction.

The Bechtel low future costs are based on the cost after the research and development of the SMES components is finished. The research needed to reduce the costs is the research requested by the Wisconsin group. Five tasks would be completed in the proposed four year 15 million dollar program:

1. Component research and development (conductor, struts, helium container, trench and fabrication).

2. Small storage magnet test coil construction (10 kWh storage system).
3. Optimized design for 100 MWh to 10,000 MWh systems.
4. Detailed conceptual design for cost and performance estimate.

Leading to:

5. Decision to construct and test an 100 megawatt hour demonstration storage unit.

The four-year request for D.O.E. funding would be as follows:

FY-83*	$ 2,957,000
FY-84	4,287,000
FY-85	4,139,000
FY-86	3,417,000
TOTAL	$14,800,000

The Wisconsin research has reached the critical stage. We are testing 3/8 inch conductors instead of full size 5 1/2 inch conductors. We are testing small mechanical struts of epoxy-fiberglass instead of 6 ft. struts. A large 18 ft. diameter helium container for the test storage superconductor coil is required. A large 16 ft. diameter storage coil should be built. We need to employ manufacturing firms to produce conductors, struts, liquid helium containers, coil mounting struts, and electrical circuitry to test the SMES concept. The funds and time needed are 15 million dollars and four years to complete research and build and test the small storage coil.

*Itemized by Congress in the FY-83 Continuing Resolution for Physical and Chemical Storage.

The object of this experiment is to test a finished complete small scale 10 kW system and to keep good records on industrial manufacturing and assembly costs. After operation and cost experience is gained then an informed decision can be made as to continuation, which could be to build a 100 MWh demonstration unit to be tested in a utility system. The Wisconsin utilities agree to the installation and test of the 100 MWh unit in the Wisconsin system for the benefit of the national electric industry.

Wisconsin requests direct funding by Congress because SMES is important to the U.S. Of all storage options, only SMES shows potential to provide 15% the total electrical power capacity of the U.S.

MADISON GAS AND ELECTRIC COMPANY
100 NORTH FAIRCHILD STREET
MADISON, WISCONSIN

DONALD J. HELFRECHT

Donald J. Helfrecht, President and Chief Executive Officer of Madison Gas and Electric Company (MGE), attended the U. of W. - Madison where he earned his B.S. degree in Electrical Engineering in 1944. Following a tour in service where he served as 1st Lieutenant in the Signal Corps, he joined MGE in September, 1946.

He became Executive Vice President of the Company in 1974 and was elected President in 1976. He has been a Director of MGE since 1972.

Helfrecht has been active in industry organizations for many years. He has served on various committees of the Wisconsin Utilities Association, the Edison Electric Institute, and the Wisconsin-Upper Michigan System. He is a past chairman of the Madison Section IEEE. He was elected president of the Wisconsin Utilities Association for the administrative year 1979-1980 and is president of the Wisconsin Electric Utilities Research Foundation. He is also a director of the First Wisconsin National Bank of Madison, the Methodist Hospital Corporation, and the Madison United Hospital Laundry.

He is a member of the Wisconsin and National Society of Professional Engineers, Institute of Electrical and Electronics Engineers, Madison Technical Club, University of Wisconsin Foundation, Kilowatt Klub, Madison Rotary, and a past member of Madison-West Rotary. He was designated Engineer of the Year in Industry for the Southwest Chapter, WSPE, in 1977 and 1981. He received a Distinguished Service Citation from the University of Wisconsin in 1981 for contributions in the field of engineering.

He is a member of the Dane County Public Affairs Council, serving three years on the Steering Committee; Central Madison Council; City of Madison Mayor's Arson Task Force; Capital Funds Committee; Civic Progress Group; the Greater Madison Chamber of Commerce; the Dane County Executive Management Commission; and the U.W.-Madison College of Engineering Industrial Liaison Council.

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PERSONAL: Born March 10, 1923 in Bladen, Nebraska

UNIVERSITY OF WISCONSIN-MADISON APPOINTMENTS:

Professor, Nuclear Engineering and Metallurgical & Mineral Engineering

Director, Applied Superconductivity Center

Manager, Superconductive Magnetic Energy Storage Program

EDUCATION:

A.B.	Physics	University of Nebraska	1944
M.S.	Physics	University of Minnesota	1950
Ph.D.	Physics	UCLA, California	1958

RELATED EXPERIENCE:

Visiting Scientist
Nuclear Physics
University of Bonn
Bonn, Germany 1958-60

Research Physicist, Applied Superconductivity
Oak Ridge National Laboratory
Oak Ridge, Tenn 1960-63

Supervisor, Applied Superconductivity
Atomics International
Los Angeles, California 1963-68

STATES IN WHICH REGISTERED

Professional Engineer, State of Wisconsin

MAIN AREA OF RESEARCH:

Superconductivity studies, particularly research, development and design of superconducting devices and magnet systems applied to energy storage and fusion systems.

Mr. **Valentine**. Thank you very much, sir.

Mr. Endahl?

STATEMENT OF LOWELL J. ENDAHL, MANAGER, ENERGY RESEARCH AND TECHNOLOGICAL DEVELOPMENT, NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION

Mr. **Endahl**. Mr. Chairman, members of the committee, my name is Lowell Endahl, manager of energy R & D for the National Rural Electric Cooperative Association [NRECA], as you perhaps know, is a national service organization for some 1,000 nonprofit rural electric systems throughout the country which serve about 25 million people in 46 States.

We appreciate the opportunity to present the membership's views on the electric energy systems and storage programs. We are deeply concerned that the electric energy systems and Storage aspect of the Federal program is constantly undervalued and consequently underfunded. Someone mentioned the budget cuts over the last several years. In 1981, electric energy systems had a $35 million budget. That has been cut to $21.3 million in 1982, to $17.2 million in 1983, and now we understand that the administration's request for this program is down to only $12.7 million for fiscal year 1984. The cutback is not only in the funding but in the staffing. There are only 4 professionals working in this area now compared to 25 or 30 back in 1981, and we believe that it is time to reverse that trend.

We were encouraged earlier this year when President Reagan, in his state of the Union address, emphasized the need for greater attention to research as the tool for growth. Then the spokesman for the Democratic Party, in the response statement, also gave his strong support for research, listing research and development as the No. 1 priority for enhancing the long-term economic welfare of this Nation.

At the NERCA annual meeting which was conducted in early February, attended by about 11,000 people, the NRECA membership commended the President and the Democratic Party for their views on research, and they developed a number of resolutions which I would like to have attached or included for the record.

One of those resolutions in particular, "Research for Growth and National Security," expressed strong support for a well-funded, long-range commitment for electric energy systems research and development and fuel cell development. That resolution urged a minimum fiscal year 1984 funding of $32 million for electric energy systems research, approaching the 1981 level of $35 million, and $33 million for utility-size fuel cell research and development.

The resolution points out that EES is involved with several programs of critical national importance. Among them is the study of the effects of electromagnetic pulse [EMP] which, in the event of strategic military weapon explosions in the atmosphere, could disrupt communications and immobilize the entire electric generation and delivery system in this Nation. The resolution also cited examples of other projects which require strong support, including technologies for improving efficiency and reliability of power generation, transmission and energy storage, and the electric field effects from high-voltage transmission lines. The National Rural Electric Cooperative Association also supports greater research efforts in superconducting technology applications, systems control and analysis, and advanced electric energy battery storage.

Another resolution that was adopted at each of the NRECA 10 regional meetings throughout the country and then reaffirmed by the membership at the annual meeting is titled, "Support for Federal Energy-Related Research," and that resolution speaks to the Rural Electric concerns over several points. First is the prevalent mistaken view that the industry is in a position to carry forth and complete the research and development effort that Government abandons.

I think the Electric Power Research Institute has done an excellent job in showing cooperation and accepting much of the burden for those projects that have been discontinued or reduced, and the rural electric systems are participating in the Electric Power Research Institute. But the industry itself has severe capital limitations that prevent it from carrying out many of the longer-range, and what it considers high-risk research projects.

The other aspect of the resolution dealt with the so-called brain drain caused by the dismantlement of experienced research teams within the Department of Energy—I want to speak a little bit more about that later—and the uncertainty caused by funding projects on a year-to-year basis when a long-term commitment is essential for continuity and production efficiency.

We believe that important energy research projects are in danger of being killed in a couple of ways: one, by drastically reducing and eliminating the funds, and then by decimating the staff that is required to manage those programs. As I mentioned, only 4 professional people remain of the technical staff of 25 to 30 that were employed some 3 years ago, and we believe it is time to reverse that trend.

The NRECA membership resolution refers to this as a brain drain, and it really is. Without consistent and realistic Government support, many promising research projects may never be brought to a productive conclusion. Scientists and engineers who are knowledgeable in this research will be forever dispersed, and their expertise in these fields lost. This lack of Federal support for important research at this critical stage means not only a loss of beneficial technology, but also a loss of America's scientific leadership among the nations of the world.

The rural electric systems own and operate about 40 percent of the distribution lines in the Nation, and so we have a special interest in the electric energy systems work. A host of new problems are beginning to surface for rural electric systems and other utilities, with their new emphasis on dispersed generation and with their efforts to plan operations with lower reserve generating capacity and greater use of load management.

Now these trends could have an adverse effect on system reliability, and we need new major emphasis on reliability concepts and methods, on the impact of solid state equipment on electric utility networks. We need to determine in advance the vulnerability of interconnected utility networks to unexpected events, including severe weather disturbances and others that have already been mentioned.

New communications and control approaches utilizing fiber optics and laser technology show promise, but a lot more study needs to be made on these. We should have a major program in this area, as well as on advanced materials research. Major progress has been made in development of new materials which could improve equipment and system efficiency and performance but, again, more basic research is needed in this area.

I understand that it is possible that new conductors could be developed that would be superior to copper and aluminum. In addition, I think that work is needed to develop more effective insulation for underground conductors. We have rural electric systems that are beginning to replace their underground cable in as little as 5 years. A major effort needs to be made in that area.

Rural electrics strongly support the research work underway on the extra high voltage transmission studies relating to electric energy field effects. We have a resolution on this topic.

We have gone on record in the past supporting storage battery research for utility applications, and we were disappointed last year when the SPEED program—storage battery electric energy demonstration—which would have involved the Wolverine and Northern Michigan electric cooperatives was terminated. However, that project now has been picked up and scaled down somewhat by EPRI, but we believe that EES should be involved, at least to the extent of EPRI, in funding of that kind of a program and in the BEST facility, the battery energy storage test facility.

As has already been mentioned, it is important to note that efficient battery storage could make a significant contribution to the effectiveness of load management schemes, and also to the use of dispersed generation systems that involve intermittent energy sources such as solar and wind.

Research programs cannot be turned on and off like a faucet. Somehow a plan needs to be devised to commit funds to research projects and programs on a multiyear basis, but with some sunset provisions, to provide the necessary continuity and thrust for the most productive and cost-effective use of research dollars. Such a plan, we believe, would give industry the confidence that it needs to participate in these projects to the maximum extent possible.

It is also important that an EES utility-oriented umbrella type of program be continued at an effective level because of its economic and national security implications. Our ability as a Nation to move large amounts of power safely and efficiently over high-voltage transmission lines and, conversely, to utilize dispersed generation and energy storage effectively in times of emergency, is of greater importance today than ever.

We appreciate the opportunity to present these views.

[The prepared statement of Mr. Endahl follows:]

STATEMENT OF
NATIONAL RURAL ELECTRIC COOPERATIVE ASSOCIATION
to the
ENERGY RESEARCH AND PRODUCTION SUBCOMMITTEE OF THE HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
HEARING ON
DOE ELECTRIC SYSTEMS AND ENERGY STORAGE RESEARCH AND DEVELOPMENT
Washington, D.C.
March 17, 1983

Madame Chairman and members of the Committee: My name is Lowell J. Endahl, manager of Energy Research and Technological Development for the National Rural Electric Cooperative Association (NRECA). We appreciate the opportunity to present the NRECA membership views with respect to the U.S. Department of Energy activities in Electric Energy Systems and Energy Storage.

NRECA is the national service organization which represents nearly 1000 non-profit, consumer-owned rural electric systems which deliver electric power to approximately 25 million people in the rural and sparsely populated agricultural areas of 46 states. The small cooperatively-owned electric utilities are located in about 2,600 of the nation's 3,100 counties, and they own and operate more than 40% of the distribution lines in the nation to serve about 9% of the population.

Specifically we would like to comment on the continued need for strong Federal support (funding and staffing) for Electric Energy Systems and Energy Storage research programs. We are deeply concerned that the importance of this aspect of Federal research is constantly undervalued--and consequently underfunded. Electric Energy Systems has received drastic budget cuts over the past several years--from $35 million in FY '81 to $21.3 million in FY '82 to $17.2 million in FY '83. Now we understand that the Administration's budget request for FY '84 shows another major cut to only $12.7 million. This trend can only indicate disinterest and lack of concern for Federal responsibilities in this important area of research relating to national security and economic development.

We were encouraged when President Reagan in his State of the Union Address, earlier this year, emphasized the need for greater attention to research as "the tool for growth". The spokesmen for the Democratic party, in a response statement, also gave strong support for research, listing "Research and Development" as the number one priority for enhancing the long-term economic welfare of this nation.

At the recent NRECA annual meeting (January 31-February 2), attended by more than 11,000 people (mostly directors and managers of rural electric systems), the NRECA membership commended the President and Democratic party for their views on research and adopted several resolutions on energy issues of concern. (Resolutions attached.)

One resolution in particular, "Research for Growth and National Security" expressed strong support for "a well-funded, long-range commitment for Electric Energy Systems (EES) research and development and fuel cell development". It pointed out that "These areas have national security implications as well as the potential for providing opportunities for growth and energy self sufficiency".

That resolution urged minimum FY-84 funding of $32 million for Electric Energy Systems research (approaching the 1981 level of funding--$35 million) and $33 million for utility size fuel cell research and development.

The resolution points out that EES is involved with several programs of critical national importance. Among them is the study of the effects of Electro Magnetic Pulse (EMP) which in the event of strategic military weapon explosions in the atmosphere, could disrupt communications and immobilize the entire electric generation and delivery system in this nation. The resolution also cited examples of other EES projects which require strong support including technologies for improving efficiencies and reliability of power generation, transmission and energy storage, and the electric field effects of high voltage transmission lines. Rural electric systems also support greater research efforts in superconducting technology application; systems control and analysis; and advanced electric energy (battery) storage.

Another resolution that was adopted at each of the NRECA ten regional meetings last fall, and reaffirmed by the entire membership at the annual meeting is titled "Support for Federal Energy-Related Research". That resolution speaks to the rural electric concerns over:

. The prevalent, but mistaken view that industry is in a position to carry forth and complete the research and development efforts that government abandons. (The Electric Power Research Institute has shown excellent cooperation in accepting as much of the burden as possible, but it and the entire utility industry have severe capital limitations that prevent them from carrying out more long range, high risk projects.)

. The so-called "brain drain" caused by the dismantlement of experienced research teams, and

. The uncertainty caused by funding projects on a year to year basis when a long term commitment is essential for continuity and production efficiency.

The following resolution on "Support for Federal Energy-Related Research" was adopted by the NRECA membership February 2, 1983:

RESOLUTION NO. J-1

Support for Federal Energy-Related Research

America's energy future and economic health are dependent upon the federal government's consistent and aggressive involvement in energy-related research and development, and upon its ability and willingness to maintain continuity in its research efforts.

Rural electric cooperatives are concerned about:

> The trend toward shifting the responsibility for major research (including costly, high-risk, short and long range projects) to the private sector;
>
> Proposals to abandon significant federal projects at a point where results could be attained with modest additional funding;
>
> The dismantlement of experienced research teams and the subsequent loss of trained personnel so vital to continued growth of American industry (The economic loss as a result of this "brain drain", as well as loss of important projects and research momentum, will give even greater competitive advantage to other industrial nations which provide substantial research support to its industries); and
>
> The uncertainty (because of annual Congressional appropriations process) of the level of federal support for projects--or whether they will be continued on a year to year basis (This is a costly and inefficient way to conduct research.)

Rural electric cooperatives are ready and willing to carry their fair share of the research burden, and they have been participating in major R&D efforts by their voluntary contributions to the Electric Power Research Institute (EPRI). However, the electric utility industry, which is already shouldering a major financial burden in providing for the energy needs of this nation, is not in a position to make major investments on long-range, high risk research and development projects which do not offer immediate or even near-term solutions to our energy needs.

We, therefore, urge the Administration and Congress to establish and support a strong energy research organization to carry out the energy research needs of this nation and with a commitment and budget to carry out plans and projects to completion. Federal support and funding are particularly needed in areas of electric utility research which are considered high-cost and high-risk, with the ultimate objective of achieving greater efficiencies in the electric industry to help stabilize energy costs (i.e. electric energy systems and fuel cell research).

Important energy research programs are in danger of being killed in two ways--by drastically reducing or eliminating project funds; and by decimating staff required to manage the programs. The Electric Energy Systems Division, which has had a superb record of conducting productive research, is a good example of what has happened. The threat of a program being starved out of existence has demoralized and caused many members of a very competent technical staff to seek more secure, and more rewarding employment elsewhere. Only four professional people remain of a technical staff of 25 to 30 employed in the Electric Energy Systems group three years ago. It is time to reverse this trend.

The NRECA membership resolution refers to this as a "brain drain", and indeed it is. Without consistent and realistic government support, many promising research efforts may never be brought to a productive conclusion. Scientists, and engineers who are knowledgeable in this research will be forever dispersed and their expertise in these fields lost. Thus lack of Federal support for important research efforts at a critical stage means not only a loss of beneficial technology, but the loss of America's scientific leadership among the nations of the world.

Rural electric systems which own and operate over 40% of the electric distribution line in the nation and serve in the sparsely settled areas of the country, have a special interest in the research being performed by the Department of Energy in Electric Energy Systems and Energy Storage.

A host of new problems are beginning to surface for rural electric systems and other utilities with the emphasis on dispersed generation, and with efforts to plan operations with lower reserve generating capacity and greater use of load management. These trends could have an adverse effect on system reliability. We need major emphasis on new reliability concepts and methods and of the impact of solid state equipment on electric utility networks. We need to determine, in advance, the vulnerability of interconnected utility networks to unexpected events, including severe weather disturbances, and develop and prove out new concepts for protective systems.

New communication and control approaches utilizing fiber optics and laser technology show promise, but require much additional study for use in the electric utility industry. EES should have a major program in this area, as well as in advance materials research. Major progress has been made in the development of new materials which could improve equipment and system efficiency and performance, but more basic research is needed to understand the basic structure and physics of these new materials. It is possible that new conductors could be developed which would be superior to copper and aluminum. In addition, work is needed to develop a more effective insulation for underground conductor. In many areas utilities are faced with the problem of replacing underground conductor in five years or less.

Rural electric systems strongly support the research work underway on Extra High Voltage (EHV) Transmission and studies relating to electric field effects (resolution attached). Experiences of utilities in acquiring rights-of-way and constructing EHV lines have revealed serious misconceptions, mystique, and fearfulness on the part of the general public as to the electric field effects on vegetation, animals, and even people living near EHV lines. Results of the research work are urgently needed, and the objectivity and involvement of the Federal government is essential to guarantee acceptance of the results.

We have gone on record in the past supporting storage battery research for utility applications, and we were disappointed when the DOE sponsored Storage Battery Electric Energy Demonstration (SBEED), which would have involved Wolverine and Northern Michigan Electric Cooperatives, was terminated. Now a much scaled down version of that project is being carried out by EPRI as a part of the work in the Battery Energy Storage Test (BEST) facility program for advanced battery development and testing. We believe that EES should be involved at least to the extent of EPRI in the research and development of load leveling batteries for utility applications. Next generation prototype batteries should be completed and tested, but that effort would be unnecessarily delayed, or perhaps never completed, without DOE support. It is also important to note that efficient battery storage could make a significant contribution to the effectiveness of load management schemes, and also to the use of dispersed generation systems that involve intermittent energy sources such as solar or wind.

Small scale hydro research and development efforts also deserve support, particularly in the area of improving economics and reducing costs for prefabricated units including the civil works (dams, etc.) Support for feasibility studies would be useful, as would environmental studies relating to minimum stream flow requirements.

A Consistent Program is Needed

Research programs cannot be turned on and off like a faucet. Somehow a plan should be devised to commit funds to research programs or projects on a multi-year basis (but with sunset provisions) to provide the necessary continuity and thrust for the most productive and cost-effective use of research dollars. Such a plan would also tend to give industry the confidence that it needs to participate in these research programs to the maximum extent possible.

It is also important that the EES utility oriented umbrella type of program be continued at an effective level (we suggest $32 million) because of its economic and national security implications. Our ability, as a nation, to move large amounts of power safely and efficiently over high voltage transmission lines; and conversely to utilize dispersed generation and energy storage effectively in times of emergency is of greater importance today than ever. To starve, through lack of funds, that portion of research that concerns itself with these issues cannot be in the national interest.

We thank you for the opportunity to express these views.

NRECA Annual Meeting 1983

RESOLUTION J-2

SUBJECT: Research for Growth and National Security

President Reagan, in his recent State of the Union Address, emphasized the need for greater attention to research as "the tool for growth." We commend the President for voicing strong support for research; and also we commend the Democratic party, which in its response statement, listed "Research and Development" as the number one priority for enhancing the long-term economic welfare of this nation.

We subscribe to this philosophy and urge prompt by-partisan action by the Administration and the Congress to establish a strong, well-funded federal research and development program.

Specifically, we support a well-funded, long-range commitment for Electric Energy Systems (EES) research and development and fuel cell development. These areas have national security implications as well as the potential for providing opportunities for growth and energy self sufficiency.

We therefore urge the following:

*Minimum funding of $32-million for FY-84 for Electric Energy Systems research within the Department of Energy. EES is involved with several programs of critical national importance. Among them is the study of the effects of Electro Magnetic Pulse (EMP) which in the event of strategic military weapon explosions in the atmosphere, could result in a pulse from scattering gamma rays that could create a surge 10 to 100 times faster than a lightning stroke. Such a pulse could disrupt communications and immobilize the entire electric utility industry. Other EES projects which require strong support include system technologies involving improving efficiencies and reliability of power generation, transmission and energy storage, and the electric field effects of high voltage transmission lines.

*A five year commitment, with a minimum of $33-million for FY-84, for fuel cell research and development. The potential offered by fuel cell technology for highly efficient, dispersed electric power generation (so essential to national security) is enormous. Along with the potential economic advantages, the fuel cell has other very desirable characteristics (environmentally benign, short lead time for installation, modular design, and favorable load-following capabilities) which makes it truly a "tool for growth."

NRECA Annual Meeting 1983

RESOLUTION J-3

SUBJECT: Priorities for Federal Energy Related Research

To meet America's future energy needs, we must develop every practicable energy source that shows promise of becoming feasible and environmentally acceptable through technological research and development.

Among projects that need adequate funding are: electric field effects; basic transmission and distribution systems research; superconducting technology application; systems control and analysis; and advanced electric energy (battery) storage.

Other technologies which show potential for commercialization and which deserve continued or increased funding and support by the federal government include the following:

*Fuel cell research and development;
*Gas cooled and fast-breeder reactors;
*Small-scale hydro;
*Geothermal (including co-op initiated projects such as the Raft River Geothermal Project, and other such projects in the Texas/New Mexico area);
*Peat, lignite and coal technologies (including gasification, liquefaction, fluidized bed combustion and MHD);
*Energy management and storage technologies (including compressed air, underground pumped hydro and battery storage);
*Solar energy systems (including residential heating and cooling, solar thermal, and photovoltaic generation of power); and
*More efficient small-and medium-scale power generation systems which can utilize coal and/or waste products and which can be used in a co-generation mode.

We urge that in development and demonstration of each of these technologies special recognition and attention be given to their impact on, and compatibility with, electric utility systems. We further urge the federal government to coordinate these research efforts with EPRI.

PREVIOUS RESOLUTIONS RECONFIRMED BY NRECA MEMBERSHIP

at the NRECA Annual Meeting in Las Vegas on February 2, 1983

99. FEDERAL SUPPORT FOR FUEL CELL COMMERCIALIZATION—Rural electric cooperatives have great interest in the development of fuel cell power plants because of significant advantages not found in conventional generating equipment. These characteristics show promise of economic benefits for the consumer, improved service availability, conservation of fuel resources, and a cleaner environment.

Commercialization of fuel cell power generation is so near, yet so far from being achieved. The phosphoric acid fuel cell has been developed to the point of large-scale demonstration at the power plant level. But the continued commercial development of the fuel cell continues to need major federal government financial support.

The next step in establishing commercial viability involves broad exposure in the market environment. The risk of proceeding as a strictly private investment has become unacceptably high, due to the economic climate and changing and unpredictable government involvement in utility decisions.

It is both essential and proper that the federal government assume a significant portion of the financial burden. We urge the Congress through the appropriate federal agency to support a comprehensive integrated program with all segments of the utility industry to provide a basis for commercial fuel cell power plant development for electric utility service. (J-1981)

100. EXTRA HIGH VOLTAGE TRANSMISSION LINE RESEARCH—The increased use of extra high voltage (EHV) overhead transmission lines for transmitting electric power by rural electric cooperatives is essential if we are to continue to provide the electric power needs of rural America. Recent experiences in acquiring right of way and constructing such EHV lines have revealed serious misconceptions, mystique and fearfulness on the part of the general public as to the electric field effects on vegetation, animals and even people living in close proximity to such EHV lines.

Although such concerns are not supported by scientific evidence, we have an urgent need to provide positive, scientifically demonstrated evidence that there are no significantly adverse effects upon vegetation, animals and people living in close proximity to such EHV lines. NRECA urges the Congress and the appropriate federal agency to adequately fund electric fields research work involving both alternating and direct current overhead EHV lines and disseminate such information to the public. (J-1981)

35. SEEKING ENERGY SOLUTIONS THROUGH ELECTRIC POWER RESEARCH INSTITUTE (EPRI)—Spiraling fuel costs, dwindling energy resources, higher costs of basic construction materials and high costs of capital have had serious impact on every rural electric system. As cooperatives we have a moral responsibility and obligation to our consumers to make a significant commitment to research and technological development in an effort to utilize new sources of energy and seek more economical ways to supply consumers' electric power needs at reasonable costs.

To that end NRECA member systems have endorsed the Electric Power Research Institute (EPRI) as a practical way of conducting research together with other segments of the electric utility industry. Since our fundraising efforts began, rural electric systems have invested millions of dollars in support of EPRI research. This is in addition to their commitments in support of the liquid metal fast breeder reactor (LMFBR) demonstration program. These commitments are visible evidence of rural electric response to their challenge.

We therefore urge that each and every rural electric system assume its rightful share in the research burden and opportunities by participating voluntarily in the NRECA-EPRI research fund according to the industry-wide formula.(J-1977)

14. ELECTRIC VEHICLE RESEARCH—A viable electric vehicle would significantly reduce the consumption of non-renewal resources and help to eliminate the major source of air pollution. Research toward developing such a vehicle is now underway, and the successful completion of such efforts could significantly alter the load patterns and requirements of rural electric systems. We support electric vehicle research efforts now underway and urge further involvement and effort by others, including the federal government, to expedite this important development. We also urge that in conjunction with this research studies be undertaken to determine the changes in electric system loads that may result from such a development.(J-1975)

Mr. Valentine. Mr. Endahl, thank you very much.

Mr. Winn, do you have any questions before you leave?

Mr. Winn. No questions. Thank you very much.

Mr. Valentine. Thank you, sir.

Mr. Endahl, most of the co-ops that you represent are distributors, aren't they? Relatively few of them are producers of energy.

Mr. Endahl. Yes, that is correct. We have some 936 that are distributors of electric power but many of them are organized through their own generation and transmission cooperatives, so there are over 60-some generation and transmission cooperatives. Those G and T's provide about 40 percent of all the electric power used and distributed by these distribution systems.

Mr. Valentine. You might have mentioned this. If so, I apologize to you for asking this question, but does your organization, sir, have its own independent research and development program where the funds are taken from your different members and contributed to that work?

Mr. Endahl. Many of the rural electric systems are supporting the Electric Power Research Institute. As a part of that program, those that contribute to EPRI through NRECA have elected to take 20 percent of that contribution and pool it at NRECA for use in sponsoring small research projects that are of special interest to the rural electric systems. One of those projects had to do with the stray voltage concern, which is a major concern for dairy farmers these days.

Mr. Valentine. Are all of the rural co-ops in the Nation members of your association, or is it voluntary?

Mr. Endahl. It is a voluntary organization and approximately 98 percent of them are members of NRECA.

Mr. Valentine. Mr. Fichett, I have a couple of questions: The Bechtel/General Atomic study estimates that present capital costs for a more economical superconducting magnetic storage ring for load-leveling applications would cost $1 billion. Do you agree with that?

Mr. Fickett. The study you refer to is not issued as a report at this date. The numbers are continually being revised. We think the report will probably be on the street this summer.

The present number, as I recall it, for today's technology would be about $1.3 billion for a 1,000 megawatts 5,000 megawatt-hours plant. They also project that gains from research into materials or creative design concepts could reduce that number to about $1,000 per kilowatt or $1 billion in the next 5 years, and if one projects beyond 5 years, that number could come down to something like $700 million or about $700 per kilowatt in the longer-term future.

Mr. Valentine. Are you prepared to tell us what work the EPRI is doing in investigating electromagnetic pulse effects?

Mr. Fickett. I would like to refer that question to Mr. Porter.

Mr. Porter. Really, all we are doing is following the work that is being done by DOE. We have no active programs in it. It is the knowledge of atomic weapons and things like that and their effects that we don't have.

Mr. Valentine. Thank you, sir.

Mr. Endahl, are you in a position to express an opinion, sir, as to the current state of systems reliability and what measures could be taken to enhance it?

Mr. ENDAHL. The question of reliability is a complex one. It is one in which the utilities, when they become interconnected with grids throughout the country, become more dependent upon one another. I think we will find as we try to operate closer to the marginal production, that we could have increasing problems in this area.

As I mentioned earlier, the utilities are trying to decrease their reserve margins by curtailing or delaying construction of new plants. They are trying to use load management equipment, and when you cut that reserve margin you are asking for some new reliability problems that we probably have not experienced. The current state of reliability of electric power supply for rural electric cooperatives is generally very good. But if we should experience very rapid growth for a few years the picture could change substantially.

Mr. VALENTINE. From your vantage point, do you see a real need for these energy storage systems? If so, do you have a preference from your vantage point as to what this system should consist of?

Mr. ENDAHL. I am not sure I understand. A preference as to the type of energy storage system?

Mr. VALENTINE. Yes.

Mr. ENDAHL. We are looking for the most economical and most effective energy storage system. We think we could make effective use of energy storage systems to improve efficiency. Soyland Power Cooperative is currently involved with compressed air storage, and that was a research program that the Department of Energy supported early on. As a result of DOE's program there will be a compressed air storage project built out there at Soyland in Illinois. We are using hydro storage and we would use battery storage if it were available.

Mr. VALENTINE. Do your members have the incentive programs that power companies have become interested in lately to encourage the members or the users to conserve energy and be conscious of the so-called peak load times and that sort of thing?

Mr. ENDAHL. Yes. Rural electrics have some unique programs. One example is the dual fuel program that Minnkota Power Cooperative in North Dakota has in effect. With that program, the consumer uses a dual fuel heating system, with the electricity used during off-peak hours and oil or gas used only during peak periods.

It does this conversion by use of a device referred to as a Graety bridge. These are well-known devices; they are used in the North-South intertie at either ends of those lines. The efficiencies of those devices on one way through is 1½ percent for that type of high voltage direct current. Therefore, for our device, it is twice that, or 3 percent, and then added to that, of course, are the losses represented by the necessity to keep this device cold, in other words, the refrigeration. Therefore, that loss is calculated at 2 percent, which gives us the total 5 percent loss or 95 percent efficiency roundtrip.

Mr. VALENTINE. Are there any unusual or extraordinary safety problems with that storage ring? Is there a problem to the environment or to people who work with it or around it that is more than would be normal in your business, with other phases of it?

Mr. HELFRECHT. Well, no, there are not. Our understanding of it is that this is a very safe device. It does not operate at high pressures. It does obviously operate at cold temperatures.

There is a question of the electromagnetic field that is created by this magnet. The design of the magnet, dependent upon which one is selected—and a low aspect ratio was selected for study by EPRI—that does indicate there would be an area obviously within the circle of the magnet itself that normally people would be kept out of, and there would be an area around the outside of it that also would be one which persons would be required to stay away from.

There has been some concern about the effect on compasses of aircraft flying over it. We have been told by pilots themselves that this is not of any concern whatsoever. As a matter of fact, there are areas in our country where magnetic compasses are affected more adversely than what this device would do. They are known to the pilots and they don't use that as a navigation device in such areas. They have their own on-board inertial guidance systems that would not be affected, and therefore, they would pay no attention to the distortion created by a magnetic compass.

There are matters with respect to environmental effects, obviously, that will require further study as this project would move forward.

Mr. VALENTINE. If there were or if it developed that there were significant problems with the directional equipment of airplanes in the future, what area of air space would that likely cover?

Mr. HELFRECHT. Well, that would only amount to a spot on the map, if you will, of about 1⅖₁₀ miles in radius or about 2½ miles across. There are already obstacles which are plotted on aircraft maps. In our own community we have TV towers out in one area of town that is known by aircraft as the tower farm or words to that effect, that they have plotted and they simply stay away from them.

Mr. VALENTINE. Can you give an estimate on a kilowatt-hour basis, Mr. Helfrecht, of the cost of a full-scale superconducting magnetic storage ring?

Mr. HELFRECHT. Well, I think Mr. Fickett basically responded to that. The current estimate by the Bechtel/General Atomic study, based on their present best estimate, is $1,330 per kilowatt-hour and subject to further research that they also felt was entirely predictible, that that could be reduced down in the $800 to $900 per kilowatt-hour range. With the ultimate program that has been planned for research it could be reduced, their current estimate was--I think as Mr. Fickett indicated—about $700 per kilowatt-hour.

Of course, it then begs the immediate next question, What does that compare to in alternative technologies? They were comparing it to a cycling coal unit which presently is running in the neighborhood of $1,370 per kilowatt.

Mr. VALENTINE. All right. Thank you, sir.

Well, since there is nobody here to object, the Chair will rule that additional testimony and information which you gentlemen desire to forward to us within a reasonable time will be made a part of the record.

I want to tell you again, for the real chairman of this subcommittee and for the members, those who were present and those who were unable to be here, that we appreciate very much the effort that went into the preparation which you have demonstrated here, and your coming here to be with us.

If there is no further business, then, we will stand adjourned. Thank you all very much.

[Whereupon, at 11:35 a.m., the subcommittee recessed, to reconvene at the call of the Chair.]

ADDITIONAL STATEMENTS SUBMITTED FOR THE RECORD

STATEMENT OF JOHN J. DOUGHERTY
DIRECTOR, ELECTRICAL SYSTEMS DIVISION
ELECTRIC POWER RESEARCH INSTITUTE
to the
ENERGY RESEARCH AND PRODUCTION SUBCOMMITTEE
OF THE HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
OVERSIGHT HEARING ON
DOE ELECTRIC ENERGY SYSTEMS AND ENERGY STORAGE
Washington, D.C.
March 17, 1983

Madame Chairman and Members of the Committee: My name is John J. Dougherty, Director of the Electrical Systems Divsision for the Electric Power Research Institute (EPRI). On behalf of EPRI, I would like to thank you for the opportunity to present to this Committee a statement outlining my views of the need for a continuing involvement of the Department of Energy (DOE) in research aimed at the area of electric energy systems.

Mr. Joseph Porter of my Division is prepared to respond to questions on electrical systems R&D.

This particular division of the DOE has a long history of close cooperation with the electric power industry that precedes the formation of the Department. It began under the Department of Interior, about 1970, when Mr. F. F. Parry began assembling a staff drawn heavily from electrical manufacturers and utilities. Later the group became a Division under the Energy Research and Development Administration (ERDA) and expanded somewhat. Finally it became the present organization when the Department of Energy was formed in 1977.

Throughout the period since I took over a counterpart Division of the Electric Power Research Institute in the then embryo organization in 1975, there has been a close spirit of cooperation and almost joint planning between the two organizations. This relationship was developed with F. F. Parry and has continued under Ray Dunlop. Since our assigned priorities and goals have frequently differed, our modus operandi has not included jointly funded projects except in the early ERDA days. Rather, we have been carrying out complementary programs and have monitored each other's programs and have held joint planning sessions whenever manpower and travel budgets have supported such activities.

At the present time, several of the prototype results of the Electrical Energy Systems (EES) research are undergoing field evaluation at the EPRI supported Waltz Mill facility in western Pennsylvania. Similarly, DOE and EPRI have made joint use of the "Project UHV" facility in Lenox, Massachusetts. Should the need arise, EES would also be welcome to utilize the Transmission Line Mechanical Research Facility (TLMRF) recently commissioned by EPRI in Haslet, Texas.

Over the past two years or so, the budget of EES has been reduced to a point where they have been unable to carry out many of their commitments to research at the planned pace. This has adversely affected such projects as the cryogenic cable development at Brookhaven, the natural follow-on work utilizing the unique synthetic tapes developed for this cable, the "Gas Insulated High Voltage Power Transformer" developed at the General Electric Company, and the Superconducting Generator Program at M.I.T., among others. Also threatened is the completion and proper implementation of a Hybrid Power System Simulator, at Purdue, on which the DOE has already spent $5 million. Many other projects carefully planned by this group have been cancelled and the present funding is inadequate to even complete programs already underway. As a consequence of the continually declining budget (at one point planned as zero) the staff has been decimated.

In my evaluation, the disbanding of this group would not be in the nation's best interests. They are currently at the early stages of evaluating the impact of an "Electromagnetic Pulse" from a high altitude nuclear explosion on the nation's power system. For obvious reasons, some of the necessary information to perform this work is highly classified and therefore the necessary facilities may only exist in national laboratories. Thus there is a strong case for Federal involvement since it may be impossible to carry out this assignment otherwise.

Finally, it is sometimes argued that the Electrical Systems Division at EPRI should pick up all the research that the EES in DOE is now carrying. This is a totally unrealistic concept in light of the realities of funding available to EPRI. The Electrical Systems Division budget for 1983 is approximately $35 million, less than the EES budget of two years ago and slightly less than the 1982 Electrical Systems Division budget. The financial condition of the utilities has inhibited any significant increase in our budget in recent years or in the near future.

It is my recommendation that the EES Division budget should be restored at least to the former level of $40 million and that adequate personnel resources be made available to plan, carry out, and oversee a research program in their area of responsibility. I pledge EPRI's full cooperation to such an activity.

ENERGY CONSERVATION: PROSPECTS FOR ENERGY STORAGE TECHNOLOGY

Fred J. Sissine
Analyst in Science and Technology
Science Policy Research Division

ABSTRACT

Energy storage systems can displace oil and natural gas use, increase the use of alternate fuels, and conserve energy. Oil import difficulties of the seventies prompted increasing Federal support for storage RD&D. However, Reagan Administration budget cuts have dramatically reduced activities—and threaten the continued existence—of the Energy Storage Program at the Department of Energy. Capital, risk and technical resource constraints prevent the private sector from picking up most curtailed Federal efforts. This paper identifies the status of storage technology developments, applications, and barriers.

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INTRODUCTION

The most familiar forms of energy storage are the dry cell battery and the lead acid battery. Other, less familiar types of energy storage devices have been used on a limited basis. Surface pumped hydro and thermal storage in the home (customer-side-of-the-meter storage) are examples of technologies which have seen more limited use. Surface pumped hydro is currently used by utilities for load-leveling. It is the most widely used form of energy storage by utilities, but the lack of acceptable sites severely restricts its potential for the future. In parts of Europe, there are many examples of consumers using thermal energy storage. They use off-peak electricity to heat water or solid material which, in turn, is used to supply space heating. Additionally, fuel cells have been used reliably in the space program to power satellites, and are of interest now to utilities for load-leveling. 1/

Since the early 1970s, there has been an increasing awareness that energy storage systems may contribute to the Nation's energy effort. Recognition of the opportunities presented by an expanded use of energy storage has prompted industry and the Federal Government to search for ways to extend the concept of storage and to increase its range of applications in utility, transportation, industrial, and residential/commercial sectors.

1/ A fuel cell does not actually store energy. However, it uses hydrogen-rich gas as a fuel, and this gas can be generated and stored during utility off-peak periods and combusted in the fuel cell to produce electricity during peak demand periods.

Congressional interest in energy storage is reflected in legislation to support the research and development of advanced energy storage technologies beginning in the 93rd Congress. 2/ Federal support for storage R&D increased steadily during the period from 1973 through 1980. However, the Reagan Administration reduced funding for this program in FY81 and has twice attempted to terminate it. The Administration's actions are consistent with an overall policy calling for reduced Federal involvement in markets which it believes the private sector can support. At present, the energy storage industry is highly fragmented. It is difficult to ascertain the size of the private investment in storage, its areas of concentration, and the likelihood that it would pick up efforts dropped due to cutbacks in the Storage Program.

Federal support has been focused on the development of electrochemical, thermal, mechanical, hydrogen, and magnetic storage devices. Support for electrochemical technologies has emphasized its potential to serve as the power source for electric and hybrid vehicles, provide utility storage (load-leveling) to improve the efficiency of power production, and increase the continuity of power provided by solar and wind energy systems. Support for thermal technologies has focused on utility load-leveling, consumer storage (utility load management), industrial storage to improve energy efficiency, and storage to improve the use of solar and wind energy systems. Support for mechanical, hydrogen, and magnetic storage has been aimed at improving the efficiency of utility power production (load-leveling) and distribution.

2/ A summary of legislation through the 97th Congress is contained in U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Research and Production. Electric Energy Systems and Energy Storage. Hearing. 97th Cong., 1st Sess. Dec. 8, 1981. Washington, U.S. Govt. Print. Off., 1982. p. 107-110 (Hereafter "Special Hearing").

By the year 2000, energy storage technologies could be providing a small improvement in national energy efficiency which, in turn, would provide a small reduction in energy demand and oil imports. A more significant reduction of oil imports is likely to be derived from improving the viability of solar and wind (renewable) energy and increasing the use of coal and nuclear power--all of which will substitute for oil and gas. Additionally, by contributing to the fuller use of base-load capacity, they may also reduce demand for utility capital investment. Regardless of whether an aggressive Federal storage program is continued, energy storage is not expected to have its full impact on the Nation's energy mix until after the year 2000. 3/

PURPOSE OF THE REPORT

The major emphasis of this report is on identifying the state-of-the-art for each energy storage technology. This includes an assessment of its progress in the R&D process, potential sectors of application and, where possible, the status of support by the private sector.

ENERGY STORAGE CONCEPT

Fuel storage and energy storage are similar in that they both provide energy systems with a buffer mechanism to mediate between supply and demand. Gasoline in an automobile tank provides daily fuel storage, natural gas kept in a dry aquifer or depleted gas field provides seasonal fuel storage, and oil storage

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3/ Personal communication with Dr. James Swisher, DOE Energy Storage Program, Sept. 17, 1982.

in tanks provides utility oil-fired peaking units with the capacity to respond quickly to changes in electricity demand. 4/

While raw fuel storage is an attractive convenience of fossil fuels, particularly oil and natural gas, the energy potential of many alternative sources, such as nuclear and solar energy, cannot be stored as fuel. Instead, this potential must be converted into a more directly usable form, such as heat or electricity, in order to store it for later use. Thus, energy storage is an intermediate phase of the energy consumption process which may occur at one or more points after initial conversion and before final utilization. This feature is illustrated in figure 1. An energy storage system makes it possible to accumulate surplus energy supplies when production exceeds demand, and to provide supplemental energy when production falls below demand. The system receives the energy output from a production technology or waste energy stream, converts it to a form of chemical, thermal, or mechanical (potential) energy which can be retained and insulated by mechanical or geological means, and reconverts it to an output which can provide energy services. Storage systems are important for many sectors of the economy since energy use can vary considerably with the time of day, from one day to another, and from one season to the next.

CURRENT APPLICATIONS

There are examples of battery, mechanical, and thermal storage applications that have been used for many years. Energy storage in lead-acid batteries is currently used, on a limited scale, for electric vehicle propulsion. In electric

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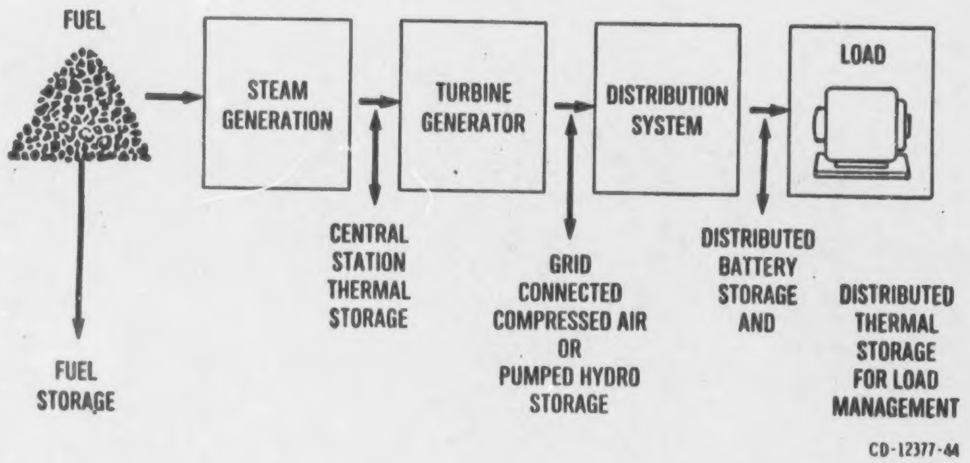
4/ Special Hearing, p. 61.

FIGURE 1

Types of Storage in Electric Power Generation and Use


FUEL
STEAM GENERATION
TURBINE GENERATOR
DISTRIBUTION SYSTEM
LOAD
FUEL STORAGE
CENTRAL STATION THERMAL STORAGE
GRID CONNECTED COMPRESSED AIR OR PUMPED HYDRO STORAGE
DISTRIBUTED BATTERY STORAGE AND
DISTRIBUTED THERMAL STORAGE FOR LOAD MANAGEMENT
CD-12377-44

Source: Swisher, James H. DOE Energy Storage Program.

utility systems, pumped hydroelectric-storage has demonstrated significant benefits as a large-scale mechanical storage system. In addition, small-scale thermal storage applications for the residential sector are widely used in Europe to reduce peak demands for electric power. Projections of current and future capital costs and efficiencies for several technologies are illustrated in table 1.

POTENTIAL APPLICATIONS

The areas of application with the most promise for oil import reductions and improved energy efficiencies through energy storage are in utility load-leveling, end-use load management, and the development of electric vehicles. In the utility sector, the daily, weekly, and seasonal variations in electric power demands often cause baseload powerplants to be used at less than 60 percent of their generating capacity. [5] These variations are illustrated in figure 2. Additionally, the importance of residential and commercial energy demand to the cycle of daily peaks is illustrated in figure 3. Intermediate- and peak-load powerplants, fired by petroleum fuels, are currently used to provide the additional requirements of peak demand periods. However, there are several reasons for increasing the use of baseload capacity to displace the use of these other facilities: baseload plants are more efficient, are less costly to operate, have better pollution controls, and can be converted to use alternative fuels.

Baseload capacity can be increased by employing energy storage during the time of off-peak demand. At different potential storage sites in the power distribution network—central stations, substations, and end-use sites—different

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[5] Kalhammer, Fritz R. Energy-Storage Systems. Scientific American, v. 241, Dec. 1979. p. 56.

TABLE 1: Capital Costs and Efficiencies for Energy Storage Devices

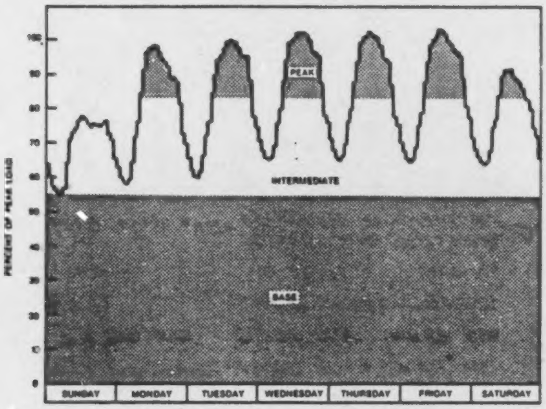
TECHNOLOGY	CAPITAL COST ($/kW)			EFFICIENCY (%)		
	CURRENT	1990	LONG-RANGE	CURRENT	1990	LONG-RANGE
Batteries	600 a/	500 a/	35-55 b/	75	75	50-60
Thermal						
Residential - Lo Temp	200	150	--	100	100	--
Industrial c/ Hi Temp	400	250	200	70	80-90	85-95
Commercial - Cool Storage	400	400	--	85-100	100	--
Seasonal Storage	--	200	--	--	60-70	--
Flywheels	--	1200	--	--	70	--
Pumped Hydro						
Above Ground	300-500	--	--	71-74	--	--
Underground	--	600 d/	500 e/	--	70	75
Compressed Air	770 f/	600 c/g/	600 c/h/	50-52	58	65-70
Hydrogen						
- Daily Use c/	40-50	45	--	68-84	68	--
- Electrolytic Production i/	400-500	300-350	200-300	60-65	70-75	80-85
Superconducting Magnetic	--	--	2600 j/	--	--	80-90

a/ Cost Basis is Stationary Battery with Five Hours Storage Capacity
b/ Cost Basis is Vehicle Battery with Two Hours Storage Capacity
c/ Cost Basis is System with Eight Hours Storage Capacity
d/ Two States of Pump-Turbine Equipment
e/ Single High Head Pump
f/ For First-of-a-Kind System of Less Than Optimal Size
g/ Hybrid System with Thermal Storage of Heat of Compression
h/ Adiabatic System with no Fuel Combustion
i/ Efficiencies for Electrolysis Plant Only
j/ Cost Basis is System with 11 Hours Storage Capacity

Source: Personal Communication with Dr. James H. Swisher, DOE, Energy Storage Program July 29, 1982.

FIGURE 2: Weekly and Seasonal Variations in Electric Demand

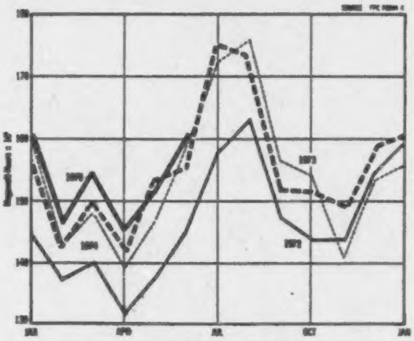
WEEKLY LOAD CURVE



Source: Project Independence, Project Independence Report, Federal Energy Administration, November 1974.

U.S. ELECTRIC GENERATION—SEASONAL VARIATIONS

The average annual load factors achievable in the generation of electric power, normally in the 60–65% range, depend largely upon the seasonal and daily variations in the demand for electricity. Seasonal peaks in demand occur in both summer and winter as a result of air-conditioning and heating and lighting loads. Daily peaks in the demand for electricity reflect the normal cycle of human activity throughout the day.

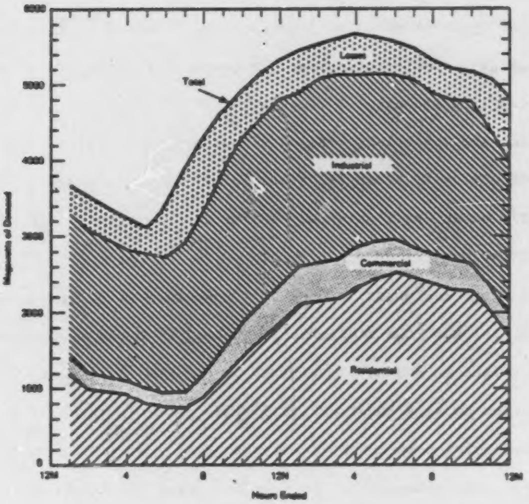


Monthly net generation of electric power by U.S. electric utility plants, 1972, 1973, 1974, 1975.

Source: FPC News, Federal Power Commission, January 2, 1976.

CRS-9

FIGURE 3: Composition of Daily Electric Demand Cycle



Source: DeSouzo, Glenn R. Energy Policy and Forecasting. Lexington, Mass., Lexington Books, 1981. p. 61.

types of storage technologies can be used for this purpose. When energy storage equipment is used in conjunction with utility-operated central stations or substations, that is, when the equipment is installed on the utility-side-of-the-meter, its effect on demand is referred to as load-leveling. This type of storage usually involves large-scale technologies. At present, surface pumped hydro is the primary load-leveling technique. Compressed air, underground pumped hydro, and magnetic storage are other large-scale systems which are being developed for load-leveling applications with central stations. Advanced storage batteries and fuel cells currently under development may be combined in modules for load-leveling use at utility substations.

When energy storage equipment is used in conjunction with consumer-owned end-use sites, that is, when the equipment is installed on the customer-side-of-the-meter, its effect on demand is referred to as load management. This type of storage application usually involves small-scale technologies. At present, thermal storage with refractory bricks and water heaters are the primary methods of using storage for load management. Storage batteries and latent heat (phase change) storage techniques under development may also be used for load management applications.

Both load management and load-leveling result in a shift in supply which evens out a utility's load profile. DOE estimates that each 1 percent increase in the market penetration of this type of energy storage capability can provide savings of about $2.5 billion in capital expenditures by the utility industry. 6/

The use of storage technology in the industrial sector can also contribute to oil displacement and fuel conversion. Displacement of oil may result from

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6/ Net Savings Due to Installation of Energy Storage Devices in the Utility-Customer System. Personal communication from Mr. James Chalmers, Project Engineer, Chemical Energy Technology Directorate, The Aerospace Corporation. Nov. 12, 1981.

the use of battery storage at industrial sites or utility grid substations to reduce peak electrical demands. 7/ An overall reduction of fuel consumption may result from the use of thermal storage to reduce time or rate mismatches between heat availability and heat demand. 8/ Furthermore, fuel may be conserved by employing thermal storage to reuse waste heat in a district heating system. 9/ Additionally, research on electrochemical storage is having a spinoff effect--the conservation of electricity in the production processes of electrolytic industries, such as aluminum manufacturing. 10/ Additionally, battery storage and on-site thermal storage can be used to even out a changing ratio of power to heat demands in order to enhance the prospects for using a cogeneration system at an industrial site. 11/

In the residential and commercial sectors, load-management can be achieved through the use of daily and seasonal storage in conjunction with utility power grids and renewable energy sources. 12/ Off-peak electric power produced by utility baseload plants can be stored at building sites to supply peak demands for space heating, air conditioning, and hot water heating. 13/ Additionally, end-use storage systems can increase the use of solar and wind energy by improving

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7/ U.S. Dept. of Energy. Energy Storage Systems: Program Summary Document. Jan. 1980. Washington, U.S. Govt. Print. Off., 1980. p. III-50.

8/ Ibid., p. III-3.

9/ Meyer, Charles F. Potential Benefits of Thermal Energy Storage in the Proposed Twin Cities District Heating-Cogeneration System. (DOE/Oak Ridge National Laboratory, Oak Ridge, Tenn.) ORNL/Sub-7604/2. Oct. 1979. p. 3-2.

10/ DOE, Energy Storage Systems, p. III-3 to III-10.

11/ Ibid.

12/ Ibid., p. III-48.

13/ Swisher, James H. Concept Statement for Distributed Thermal Storage. In Peak-Load Pricing and Thermal Energy Storage. Division of Energy Storage Systems, Dept. of Energy, July 15-17, 1979. p. 55.

the continuity of energy supply from on-site technologies. 14/ This feature is illustrated in figure 4.

For the transportation sector, electrochemical storage in rechargeable batteries and fuel cells is being explored for use in electric and hybrid vehicles. The development of such vehicles could shift fuel dependence from oil (in the form of gasoline) to coal and nuclear energy used to produce electrical power. 15/

BARRIERS TO COMMERCIALIZATION

For each type of storage technology, there may be characteristic technical, environmental, economic or institutional barriers which R&D efforts seek to overcome. Depending on the particular technology, there may be more than one barrier--and barriers may be interrelated.

In the case of underground compressed air and pumped hydro storage, the technology is sufficiently developed, but there are environmental concerns. Underground storage could contaminate or otherwise impair underground water flow regimes. The cost of addressing this concern, when combined with the costly materials and construction procedures, may inhibit the market for this system. 16/

Utility rate structures can also be a barrier to the use of energy storage technology. The use of electric heating elements to warm clay bricks for sensible heat storage for home heating is a fairly common practice in Europe. The technology is available in the United States and its environmental impact is

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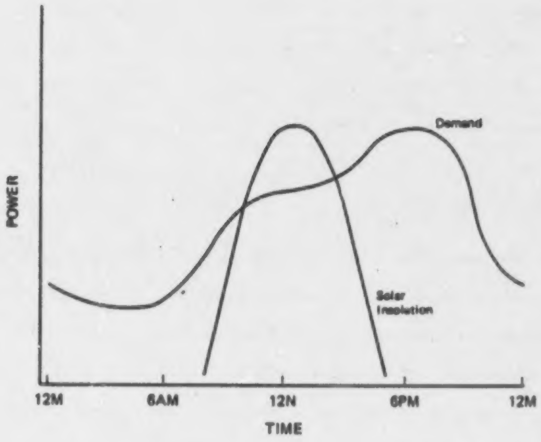
14/ DOE, Energy Storage Systems, p. III-3.

15/ DOE, Energy Storage Systems, p. I-1.

16/ Chiv, H. H. et al. Mechanical Energy Storage Systems. Journal of Energy, v. 3, May-June 1979. p. 133-134.

FIGURE 4: Comparison of Typical Solar Energy Availability and Residential Electric Energy Demand



Source: National Academy of Sciences, Energy Storage for Solar Applications. Washington, D.C., 1981.

negligible, but the flat rate structure for residential electricity provides no incentive for off-peak storage. In Europe, reduced rates (preferential tariffs) for off-peak residential power consumption were established during the 1960s. 17/

The relatively low cost of competing energy supplies poses a major economic barrier to the use of electric vehicles. The current world "glut" of available petroleum keeps gasoline prices low relative to the costs of electric vehicle operation, particularly if the costs of developing an industrial infrastructure for electric vehicles are included. If political conditions change, and petroleum availability becomes severely restricted, the price of gasoline could rise which could make electric vehicles more attractive.

THE DOE ENERGY STORAGE PROGRAM

The Federal Government has supported work on energy storage systems since 1973. Figure 5 depicts the history of Federal funding. The current Energy Storage Research and Development Program emphasizes advanced research on long-term, high-risk, but potentially high payoff storage technologies that will improve the linkages between energy sources and the processes of conversion, distribution, and end-use. 18/ The program is based on an assumption that the marketplace will determine private industry's development of near-term technologies into commercial hardware. 19/ Technologies for chemical, thermal, mechanical, and magnetic

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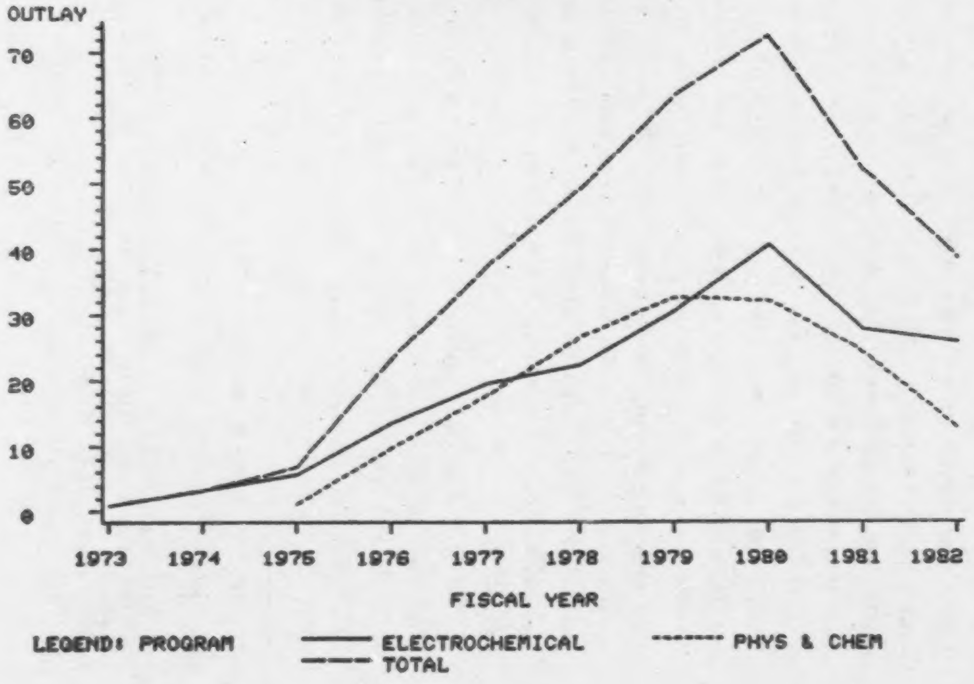
17/ U.S. DOE. Energy Storage Program. Peak-Load Pricing and Thermal Energy Storage. (Conference Proceedings) July 15-17, 1979.

18/ U.S. Department of Energy. Energy Storage Systems: Program Summary Document. Apr. 1981. Washington, U.S. Govt. Print. Off., 1981. p. III-B-1.

19/ U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Research and Production. 1982. DOE Authorization. Hearing, 97th Cong., 1st Sess., Mar. 16, 1981. Washington, U.S. Govt. Print. Off., 1981. p. 532.

FIGURE 5:

ENERGY STORAGE FUNDING TRENDS
DOE SPENDING FROM 1973 TO 1982
($ MILLIONS)



storage are being explored for applications to industry, buildings, utilities, and transportation. Applications of these technologies to different sectors is illustrated in table 2. The DOE Energy Storage Program serves as the nucleus for virtually all research and development related to energy storage within the agency. Thus, the program supports not only the utility, end-use, and renewable energy applications related to Conservation and Renewable Energy programs, but also supports some of the missions of the Nuclear Power and Fossil Fuel programs. 20/

For FY82--the Reagan Administration's first budget--the request for the Energy Storage Program totalled $38.0 million, which was $33.4 million below the FY81 appropriation before the rescission. At the subprogram level, the Administration requested $25.6 million for the Battery Program, $11.9 million for the Thermal and Mechanical Program, and $0.5 million for program management. 21/ Congress approved this sharp reduction in the Energy Storage Program when it passed the FY82 DOE authorization bill (contained in P.L. 97-35, the Omnibus Budget Reconciliation Act), adding $3 million to the Thermal and Mechanical Program. 22/

Before Congress could complete action on the FY82 DOE appropriations bill (H.R. 4144), the Administration amended its FY82 budget request, asking only for enough funding to terminate program operations. 23/ The revised proposal asked for $5.1 million for the Battery Program, $4.6 million for the Thermal

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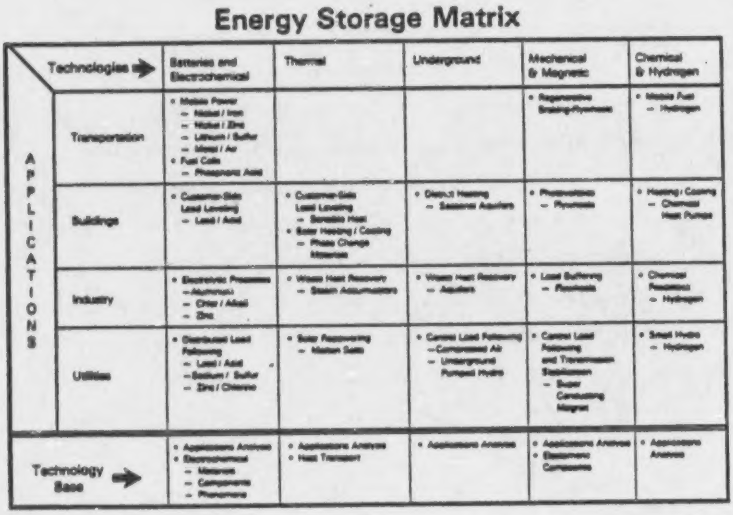
20/ DOE, Energy Storage Systems, 1980, p. III-2.

21/ Personal communication with Jeff Nita, Congressional Budget Office. Dec. 3, 1981.

22/ U.S. Congress. House. Committee of Conference. Omnibus Budget Reconciliation Act of 1981; report pursuant to H.R. 3982, 97th Cong., 1st Sess. Washington, U.S. Govt. Print. Off., 1981. 1047 p. (97th Cong., 1st Sess. House. Report no. 97-208, part 2) p. 835.

23/ DOE, FY 1982 Budget Amendment, p. 107-109A.

TABLE 2: Matrix of Storage Technologies Matched with End-Use Applications



Energy Storage Matrix

	Technologies →	Batteries and Electrochemical	Thermal	Underground	Mechanical & Magnetic	Chemical & Hydrogen
APPLICATIONS	Transportation	• Mobile Power – Nickel / Iron – Nickel / Zinc – Lithium / Sulfur – Metal / Air • Fuel Cells – Phosphoric Acid			• Regenerative Braking-Flywheels	• Mobile Fuel – Hydrogen
	Buildings	• Customer-Side Load Leveling – Lead / Acid	• Customer-Side Load Leveling – Sensible Heat • Solar Heating / Cooling – Phase Change Materials	• District Heating – Seasonal Aquifers	• Photovoltaics – Flywheels	• Heating / Cooling – Chemical Heat Pumps
	Industry	• Electrolytic Processes –Aluminum – Chlor / Alkali – Zinc	• Waste Heat Recovery – Steam Accumulators	• Waste Heat Recovery – Aquifers	• Load Buffering – Flywheels	• Chemical Feedstocks – Hydrogen
	Utilities	• Distributed Load Following – Lead / Acid –Sodium / Sulfur – Zinc / Chlorine	• Solar Repowering – Molten Salts	• Central Load Following –Compressed Air – Underground Pumped Hydro	• Central Load Following and Transmission Stabilization – Super Conducting Magnet	• Small Hydro – Hydrogen
Technology Base →		• Applications Analysis • Electrochemical – Materials – Components – Phenomena	• Applications Analysis • Heat Transport	• Applications Analysis	• Applications Analysis • Electronic Components	• Applications Analysis

Source: DOE. Energy Storage Program (Booklet).

and Mechanical Program, and $0.5 million for program management. Congress rejected this termination move by the Administration. H.R. 4144 was reported from conference on November 19, 1981, with a recommendation that funds be appropriated for the Energy Storage Program at the level authorized. 24/

The Administration's FY 1983 budget request assumes that DOE will be dismantled and seeks again to terminate the Energy Storage Program. 25/ It does, however, include $2.2 million of electrochemical research in the multisector component of the energy conservation budget. The House Science and Technology Committee's Subcommittee on Energy Research and Production dissented from the Administration's proposal to zero out the Storage Program, and instead recommended a FY83 authorization of $41.5 million for Electric Energy and Energy Storage Systems to the full committee. 26/ However, the Subcommittee on Energy and Water of the House Appropriations Committee, 27/ and the Subcommittee on Energy and Water of the Senate Appropriations Committee have recommended a $25.7 million appropriation for the program. 28/ Nevertheless, this level of appropriation, if enacted, would represent a 33 percent drop from the FY82 level.

24/ U.S. Congress. House. Committee of Conference. Making Appropriations for Energy and Water Development for the Fiscal Year Ending September 30, 1982, and for Other Purposes. Report pursuant to H.R. 4144, 97th Cong., 1st Sess. Washington, U.S. Govt. Print. Off., 1981. 44 p. (97th Cong., 1st Sess. House. Report no. 97-345) p. 26.

25/ U.S. DOE. Congressional Budget Request, FY 1983, v. 3, Energy Supply Research and Development. (DOE/MA-0057) Feb. 1982. p. 79.

26/ U.S. Congress. House. Committee on Appropriations. Subcommittee on Energy and Water Development. FY 1983 Appropriations. Statement of the Honorable Don Fuqua. Hearing, 97th Cong., 2d Sess., Apr. 1, 1982. p. 6.

27/ U.S. Congress. House. Energy and Water Development Appropriation Bill, 1983. House Report no. 97-850, 97th Cong., 2nd Sess., Sept. 21, 1982. Washington, U.S. Govt. Print. Off., 1982 p. 23.

28/ U.S. Congress. House. Energy and Water Appropriation Bill, 1983. Senate Report no. 97-673, 97th Cong., 2nd Sess., Dec. 6 (legislative day Nov. 30), 1982. Washington, U.S. Govt. Print. Off., 1982. p. 55.

SIGNIFICANCE OF THE DOE PROGRAM TO THE PRIVATE SECTOR

Beginning with FY81 rescissions, the Reagan Administration has initiated several cutbacks in the Storage Program, and has twice attempted to terminate it. The Administration has argued that recent declines in oil imports have prompted a reevaluation of the role of the Federal Government in energy. This change in role involves moving away from end-use products and toward more basic research. 29/ Mr. Joseph Tribble, Assistant Secretary for Conservation and Renewable Energy, testified that storage programs are either no longer appropriate or not of a high enough priority to continue Federal support. For this reason, he emphasized that no funds were requested for this program in FY 1983. 30/ The Administration has argued that the private sector would assume responsibility for any worthwhile developments discontinued as a result of program cutbacks or termination. 31/ Consequently, the future role of the private sector in storage developments has been a matter of congressional attention since early 1981. This attention was reflected in hearings on the Storage Program, held for the House Committee on Science and Technology in December 1981. 32/

Two major issues were raised at these hearings. One, raised by representatives of the private sector, was that the private sector would not be able to pick up all of the important storage developments that would otherwise

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29/ U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Research and Production. FY 1983 Budget Review Hearing: Electric Energy Systems, Energy Storage Systems and Small-Scale Hydroelectric Programs. Hearing, 97th Cong., 2nd Sess., Mar. 25, 1982. Washington, U.S. Govt. Print. Off., 1982. p. 3. (Hereafter cited as Budget Review Hearing.)

30/ Ibid.

31/ Ibid.

32/ Special Hearing.

be halted by cutbacks or termination of the Storage Program. Mr. Robert H. Pry of Gould Inc. testified that the potential for energy storage to reduce oil imports makes it significant to national security and welfare, but does not provide incentives for the private sector to risk its own financial resources. 33/ Dr. Jon B. Pangborn of the Institute of Gas Technology added that a Federal role is necessary to bring storage technology to the stage where individual companies can see specific applications within a near-term time frame. 34/ Also, Dr. Thomas Schneider of the Electric Power Research Institute expressed doubt that the private sector has the capability to pick up all of the significant electrochemical research being deleted from the Storage Program. He testified that market weaknesses, uncertainty of technical success, and long development times discourage large private investments in storage R&D by the electric energy industry. 35/

The other major concern was that cutbacks in Federal efforts might damage the position of the U.S. industry in domestic and international marketplaces for energy storage equipment. 36/ It was noted that much of the work being eliminated is long-range research that industry would not be able to accommodate and which, in the long run, could result in the importation of advanced technology. 37/ In particular, it was pointed out that there is a world wide "race" to develop suitable batteries for electric vehicle and utility load-leveling applications. 38/

33/ Ibid., p. 50.

34/ Ibid., p. 70.

35/ Ibid., p. 5-6.

36/ Budget Review Hearing, p. 35.

37/ U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Research and Production. Dept. of Energy Authorization for Fiscal Year 1982. Hearings, 97th Cong., 1st Sess., Mar. 16, 1981. Washington, U.S. Govt. Print. Off., 1981. p. 513.

38/ Special Hearing, p. 152-154.

TYPES OF ENERGY STORAGE TECHNOLOGIES

ELECTROCHEMICAL ENERGY STORAGE

Batteries and fuel cells are the two major types of storage technology which rely on the conversion of chemical energy to electrical energy as a basis of operation. Batteries undergo a chemical change upon conversion of stored energy whereas fuel cells, which consume an externally-supplied hydrogen-rich gas, undergo no material change.

Batteries

Energy is stored in a secondary battery (charging) by employing reversible electrochemical reactions to separate reactive materials. These materials are supplied by a liquid or solid electrolyte which connects two electrodes. The reactions take place at the electrodes by forcing an electric current to flow through the battery. Energy is recovered (discharged) by reversing the charging process--allowing the reactive materials to combine again. This recombination produces an electric current and potential difference in an electrical circuit external to the battery. 39/ The storage batteries currently being developed include conventional systems which can be operated at room temperature such as lead-acid, nickel-iron, nickel-zinc and nickel-hydrogen batteries; high operating temperature systems such as sodium-sulfur

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39/ The Aerospace Corporation. Characterization and Applications Analysis of Energy Storage Systems. El Segundo, California, The Aerospace Corporation, Dec. 1977. (ATR-77 7538-1) [NSF Grant No. AER75-20387] p. 2-90.

and lithium-iron batteries; circulating electrolyte systems such as zinc-chlorine, zinc-bromine, and iron-chromium redox batteries; and plastic (polymer) batteries.

Applications of Batteries

Batteries are being developed for: (1) electric and hybrid vehicle propulsion, (2) utility load-leveling, (3) load management, and (4) solar and wind electric energy storage. Table 3 illustrates the time frame for the development of specific battery systems related to these three areas of application. Each area of application is characterized by several approaches. The electric vehicle application requires batteries with high specific energy and energy density, which are capable of delivering high power per unit weight and volume. 40/ The development of hybrid vehicles includes the examination of battery/battery, battery/flywheel, battery/fuel cell, and battery/internal combustion engine combinations. The objective of the hybrid vehicle concept is to achieve a range of performance that is not possible with batteries alone. 41/

The major application of utility batteries is load leveling to reduce oil- and gas-fired peaking capacity, improve the overall efficiency of coal and nuclear baseload capacity, and increase the use of renewable energy electric technologies. 42/ For load leveling and industrial/commercial load management, effort is focused on the development of multi-megawatt-hour (1 to 20 MW) modular batteries, with an emphasis on energy density and long, reliable cycle life for a

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40/ U.S. DOE. Batteries for Energy Storage. Energy Technologies and the Environment. (DOE/EP-0026) June 1981. p. 408.

41/ Douglas, David L. and James R. Birk. Secondary Batteries for Electrical Energy Storage. Annual Review of Energy, v. 5, 1980. p. 67.

42/ Ibid.

TABLE 3: Projected Time Frame for Applications of Battery Storage Systems

Application	Time Frame		
	Near-Term	Mid-Term	Long-Term
Electric Vehicle	Lead-acid Nickel-iron Nickel-zinc Nickel-hydrogen Zinc-chlorine	Lithium-iron sulfide Sodium-sulfur Zinc-bromine	Aluminum-air Iron-air Plastic
Utility Load-leveling & Load management	Lead-acid (advanced) Zinc-chlorine	Lithium-iron sulfide Sodium-sulfur Zinc-bromine	Plastic Iron-chromium redox
Solar & Wind	Lead-acid (current use)	Lead-acid (advanced) Zinc-bromine	Plastic Iron-chromium redox

Source: Personal communication with Robert Meredith, DOE Energy Storage Program, August 2, 1982.

minimum of 8 to 10 years of service. 43/ For residential load management, effort is focused on the development of multi-kilowatt (1 to 1000 kW) batteries, with a similar emphasis on density and reliability. 44/

Batteries can also be used with solar photovoltaic and wind energy systems to provide some or all of the power requirements when insolation or wind is unavailable. For these applications, the battery must be highly compatible with the random function mode of solar or wind energy storage (rapid shifts among charge, discharge, and standby modes of operation). 45/ In "stand alone" systems, batteries can make it possible to maintain continuity of service, when isolation or wind is unavailable. For "utility interactive" systems, where power can be exchanged with a utility grid, batteries can be used as a temporary buffer for short periods of a daily cycle. 46/ Advanced lead-acid batteries and circulating electrolyte systems such as zinc-bromine and iron-chromium redox are considered most promising for this area of application. 47/

Advantages of Batteries

In comparison with most other storage technologies, batteries have the advantage of being modular--a factor that, for utilities, promises a relatively short lead time from order to installation, the capability to add capacity in

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43/ U.S. DOE. Batteries for Energy Storage. Energy Technologies and the Environment. (DOE/EP-0026) June 1981. p. 408.

44/ Bates, F. J., et al. Battery Storage: A Load Management Option. Columbus, Ohio: Battelle Institute, May 1982.

45/ Batteries for Energy Storage, p. 409.

46/ Douglas and Birk, p. 68.

47/ Roberts, R. Status of the DOE Battery and Electrochemical Technology Program III. McLean, Virginia, The MITRE Corporation, Feb. 1982. (MTR-81W223) p. 2-35.

small increments (5 to 10 MW), and a wider choice of sites. 48/ Since batteries can be dispersed throughout the utility system, they may also offer increased system reliability and savings in transmission. 49/ Because batteries can be operated over widely varying loads, they can respond quickly to rapid fluctuations in electrical demand. 50/ This feature may also enable batteries to serve a 5-hour duty cycle and thus find a niche between longer-cycle pumped hydro and compressed air storage devices (8 to 20 hours) and shorter-cycle, customer-side-of-the-meter water heater control devices (1 hour). 51/ Additionally, when batteries are used at part load, they are more efficient than they are at full load. This gives them an advantage over pumped hydro and compressed air storage. Because of their nature and design, battery storage plants will likely have low installation cost, be very reliable, and require little maintenance. 52/

Environmental Concerns

Increases in battery manufacturing and related industries will raise a number of concerns, including those associated with air-borne emissions, liquid effluents, solid wastes, and occupational as well as public health and safety. Health and safety hazards are associated primarily with occupational exposures to airborne dust and fumes during mining, milling, smelting, and battery manufacture, and to a lesser degree with accidental contact by employees with toxic or caustic

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48/ Electric Power Research Institute (EPRI). The New Batteries. EPRI Journal, v. 6, Oct. 1981. p. 7.

49/ Douglas and Eirk, Secondary Batteries, p. 67.

50/ EPRI, New Batteries, p. 7.

51/ EPRI. EPRI Roles in Battery Commercialization. (EPRI EM-1748) Palo Alto, Calif., EPRI, Mar. 1981. p. S-9.

52/ EPRI, New Batteries, p. 7.

battery materials during assembly or testing. For the manufacture of near-term batteries (lead-acid, nickel-zinc, nickel-iron, and zinc-chlorine), the elements lead, arsenic, antimony, nickel, zinc, chlorine, and cadmium and their compounds are of concern. 53/ Solid wastes from battery-related industries could contain these other potentially hazardous materials and adverse effects could result from the leaching of these wastes into soils, groundwater, and surface water. 54/

Near Term (Aqueous Nonflow) Systems

Presently available electric vehicles are restricted to a 50 mile range by the limited energy density of state-of-the-art lead-acid batteries. The Near-Term Electric Vehicle Battery Project, begun at DOE in 1978, is aimed at commercialization in 1986 of a commuter vehicle capable of a 100 mile range. This project is focused on the development of four types of batteries with sufficient energy density to power such a vehicle: advanced lead-acid, nickel-iron, nickel-zinc, and nickel-hydrogen. 55/

Lead-acid batteries. Lead-acid batteries are presently produced for a number of commercial applications. These include starting, lighting, and ignition batteries for use in automobiles, motive power batteries for small industrial vehicles such as fork-lifts and personnel carriers, and large storage batteries to provide stand-by electrical power. There is currently considerable R&D activity in the United States, Europe, and Japan directed toward improving the performance of lead acid batteries--especially for electric vehicle applications.

53/ Batteries for Storage, p. 414.

54/ Ibid., p. 419.

55/ Christianson, C. C., N. P. Yao, and F. Hornstra. Near-Term Batteries for Electric Vehicles. In Energy Technology VIII, 1981. Edited by Richard F. Hill. Washington, Government Institutes, Inc. p. 622.

Improvements in discharge rate performance as well as energy storage capability have been attained through developments in electrode plate design, separators, and inter-cell connectors. 56/

The amount of energy required to charge a lead-acid battery can be reduced by circulating its electrolyte. Circulation of the electrolyte corrects non-uniformities in the concentration of the sulfuric acid which otherwise impairs the acceptance of input electric current. This technique may improve the charging efficiency by as much as 10 percent. The Globe Union Company, a subsidiary of Johnson Controls, Inc., has developed an advanced lead-acid battery which incorporates this type of system. In addition, improved alloys and low-weight container materials are being developed for lead-acid batteries. 57/

Alkaline batteries. There are several potentially attractive cell combinations which utilize a nickel electrode. Of these combinations, only nickel-cadmium has been developed into a battery which is currently marketed commercially, and it is only used for small appliances such as radios and hand calculators. There is interest in R&D on nickel electrode batteries for vehicle and load leveling applications because its energy and power density potential appears to be much greater than that of lead acid batteries. However, the high cost of fabricating nickel electrodes has been a major deterrent to wider use of these batteries. 58/

Nickel-iron battery. The nickel-iron battery has a very long lifetime (20 years or more). It has been used in car lighting, industrial truck, and other

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56/ Aerospace Corporation, p. 2-95 to 2-99.

57/ Personal communication with Robert Meredith, DOE Energy Storage Program, Aug. 2, 1982.

58/ Aerospace Corporation, p. 2-99 to 2-100.

heavy duty service for over half a century. However, its higher cost, lower power density, and need for greater maintenance (watering) than lead-acid batteries resulted in a small market demand and a stagnant technology for many years. Because of the very rugged construction of this battery, the manufacturing processes are inherently costly and the resulting structure heavier than the lead-acid battery. 59/ Technical problems include (1) poor low-temperature performance of the iron electrode, (2) poor efficiency of the iron electrode on charge, and (3) difficult thermal management. Nevertheless, there has been considerable work done to attain a greater fraction of its energy and power density potential. Electrode improvements are under development in the Westinghouse/DOE program, and full size (20 to 40 kWh) batteries were tested in 1981. Eagle-Picher Industries, Inc., has also been under contract to DOE for electrode developments. 60/

Nickel-zinc battery. The lifetime of this battery has been limited by serious problems associated with the zinc electrode. The difficulty derives from the fact that zinc hydroxide, the discharged product of the zinc anode, is soluble in the electrolyte. During the charging cycle the zinc is not uniformly distributed over the electrode and has a strong tendency to form dendritic (branch-like) growths. The nonuniform distribution of zinc leads to inefficient utilization, and eventually to significant loss of capacity. The dendritic growths are a more serious concern since they can lead to short circuiting. 61/ Efforts to control these problems have not been successful. 62/

59/ Ibid., p. 2-101 to 2-102.

60/ Douglas and Birk, p. 82.

61/ Ibid., p. 82-83.

62/ Personal communication with Robert Meredith, DOE Energy Storage Program, Aug. 2, 1982.

Nickel-hydrogen battery. The nickel-hydrogen battery is air tight, maintenance free, has long cycle and shelf lives, can stand partially charged without degradation, and has a high tolerance to cell reversal and overcharge. It was developed for space satellite applications to replace nickel-cadmium batteries. The principal developers are Communication Satellites, Inc., (COMSAT) and the U.S. Air Force. Because the battery utilizes a significant amount of platinum in the construction of the hydrogen electrode, it appears to be inherently expensive. This feature may limit applications to space vehicles and platforms. However, it may be possible to improve the electrode to reduce the required platinum. This could extend the range of applications. 63/

Advanced Systems

Non-aqueous batteries. The development of advanced non-aqueous batteries is targeted at applications in electric vehicles, utility load leveling, and solar energy storage. The two major technical efforts involve the development of two high-temperature systems: sodium-sulfur and lithium-iron sulfide batteries.

Sodium-sulfur (beta) battery. This battery uses molten sodium as the negative electrode material, molten sulfur and sodium polysulfide as the positive electrode material, and beta-alumina as the solid ceramic electrolyte. It is operated in a temperature range from 575 to 660 degrees F. R&D is currently focused on safety subsystems, battery design, and large cell fabrication and testing. Major technical problems include the performance and cost of the electrolyte and overall battery performance and lifetime. This battery is the

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63/ Personal communication, Meredith, DOE, Aug. 2, 1982.

most popular of all the advanced batteries: major projects to develop it are under way in six countries, and more funds are being spent on it worldwide than on any other. 64/

Lithium-iron sulfide battery. Lithium and sulfur are attractive as electrode materials for high performance batteries because they have a very high potential energy density. As a result, they have much smaller size and weight than comparable lead-acid systems. The lithium-iron sulfide battery uses a solid lithium-aluminum or lithium-silicon alloy as the negative electrode material, and iron sulfide or pyrite as the positive electrode material. An eutectic of lithium chloride and potassium chloride is used as the molten salt electrolyte. The active materials are often contained as a powder in a flat honeycomb metallic structure, and the battery is operated at 800 to 935 degrees F.

Cells for electric vehicle application are about 300 Wh in energy capacity and for load-leveling application are about 1.0-1.5 kWh. The goal of cell development is to achieve long life and high energy density simultaneously. High energy densities are attractive for electric vehicle applications. Additionally, the inability to achieve long life with economical (compact) cell designs limits interest in the potential for utility application. 65/

Aqueous (flow) batteries. These batteries have at least one of the active materials stored external to the power-converting cell. The active material is circulated via the electrolyte during system charge or discharge. This feature makes flow systems largely immune to dendrite formation and facilitates thermal management. Additionally, it provides the major advantages of

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64/ Douglas and Birk, p. 77-78.

65/ Ibid., p. 78-79.

longer cell lives and greater system design flexibility. Three types of flow batteries are being developed: zinc-chlorine, zinc-bromine, and iron-chromium redox batteries.

Zinc-chlorine battery. In this battery, metallic zinc is the active material at the negative electrode and chlorine dissolved in the electrolyte is the reactant at the positive electrode. Zinc chloride dissolved in water is the electrolyte, consequently the system can be operated conveniently near room temperature. Zinc and chlorine are low-cost, lightweight, and readily available materials, which is one primary reason for interest in developing this system. Toxic chlorine gas is formed during the charging phase, but it is dissolved in chilled water to form an ice-like solid, chlorine hydrate, which is stored until the battery is discharged. This arrangement is illustrated in figure 6. However, a major constraint on the design of cells and batteries is that the reactants must be stored in separate places during the charge and discharge states. Technical problems involve the corrosive nature of chlorine and the need for good reaction kinetics at the chlorine electrode. 66/ Cost is also a consideration since either titanium or chromium is required as electrode material. Nevertheless, 50 kWh battery modules have been operated under laboratory conditions by Energy Development Associates (EDA). EDA is currently using zinc-chlorine batteries to power automobiles (vans). 67/

Zinc-bromine battery. This battery uses an electrolyte of aqueous zinc bromide, and either carbon or a titanium-ruthenium alloy is used as an electrode material. Operating temperature is in the range of 75 to 120 degrees F. The

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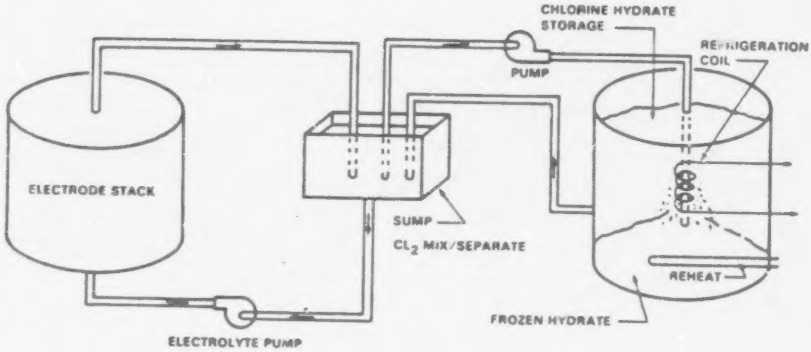
66/ Ibid., p. 74-76.

67/ Personal communication, Meredith, DOE, Aug. 1982.

FIGURE 6: Zinc-Chlorine (Circulating Electrolyte) System


CHLORINE HYDRATE STORAGE
REFRIGERATION COIL
PUMP
ELECTRODE STACK
SUMP
CL_2 MIX/SEPARATE
REHEAT
FROZEN HYDRATE
ELECTROLYTE PUMP

Source: DOE. Energy Storage Systems (1.1b/DOE), Apr. 1981.

inability to control and store bromine adequately has been the primary reason for failure to develop these cells in the past. In order to reduce the activity of the bromine and thus its solubility, it is chemically combined with a compound known as a complexing agent. The result is a heavy oil which is easily separated from the solution. Even with the complexing of the bromine, the use of a separator is required to reduce bromine's corrosion of zinc to tolerable levels. Despite this, the system appears to be somewhat simpler in design and operation than the zinc-chlorine system--a result of having to handle only two liquid components instead of three phases--gas, liquid, and solid. Gould, Inc. is carrying out a development project focused on utility applications, and Exxon is developing the system for both electric vehicle and stationary applications. 68/

Iron-chromium redox batteries. This battery converts chemical energy to electrical energy by reacting solutions of the chloride salts of chromium and iron. The two electrolytes are pumped through inert carbon-felt electrodes in a power conversion unit, where a highly selective ion-exchange membrane allows ion transfer but keeps the fluids separated. The reactant fluids are kept in separate tanks. The storage capacity of the system is determined by the amount of electrolyte in the storage tanks, while its power output depends on the size of the power conversion unit. Because the tanks and power unit are separate, each can be sized independently and thus tailored to the specific needs of the operator. 69/

Lead-acid battery lifetime is limited by the decay of the electrodes, but the redox battery lifetime is limited only by the durability of the separating

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68/ Douglas and Birk, p. 83-84.

69/ Energy Research Reports, v. 8, June 14, 1982. p. 1-3.

membrane. The National Aeronautics and Space Administration (NASA) estimates that a 20 to 30 year lifetime can be expected for the membrane. 70/ NASA also projects that small redox systems could be built for half the cost of lead-acid systems with the same capacity. 71/ The redox battery has the additional advantage of operating at temperatures of 212 degrees F or less, compared with the high temperatures required for operating sodium-sulfur and lithium-iron sulfide batteries. 72/

Metal-air batteries. These batteries use metals as the energy-producing fuels. The metal, used as the negative electrode, reacts with oxygen obtained from air drawn in through the positive electrode. The air cathode is attractive as a battery component because it contributes to a high overall energy density. Zinc-air batteries have been available for decades in limited applications. However, iron-air and aluminum-air batteries are the focus of current R&D. The development of iron-air batteries is based on long-term experience with iron electrodes and the ability to use conventional recharging methods. The primary motivation for its development is the potential for obtaining a moderately high energy density in a unit which requires relatively inexpensive materials and manufacturing techniques. The aluminum-air battery is attractive for its mechanical refueling capability. Its operation requires only periodic removal of the reaction product, addition of tap water, and refueling with fresh aluminum plates. 73/

70/ Ibid., p. 2.

71/ Ibid., p. 4.

72/ Ibid., p. 3.

73/ See Mayo, James W., et al. Energy Storage for Transportation. In Energy Technology VII, 1980. Edited by Richard F. Hill. Washington, Government Institutes, Inc. p. 634-635. Also see Roberts, R. et al. New Developments in Electrochemical Conversion, Storage, and Distribution. McLean, Va. The MITRE Corporation, Dec. 1981. p. 36-37.

Plastic (polymer) batteries. Certain plastics, known as organic polymers, can be doped electrochemically with metal in order to make them electrically conductive--like semiconductors or metals. The resulting substance is referred to as a conducting polymer or conducting plastic. The conductive polymer acts as both the electrochemically active material and the current collector.

The simplest organic polymer, polyacetylene, can be made in the form of thin, stretchable films. These films can be used as the electrode materials for batteries. By immersing two small pieces of film in a suitable electrolyte, an electrochemical cell is formed. An electrical charging process creates two conducting polyacetylene electodes that have equal but opposite oxidation states. During discharge, the electrodes become "undoped," reverting to their original neutral state. The cell can then be recharged. Since the ions move in and out of the polymer without changing their chemical state, as they do in other batteries, batteries with polyacetylene electrodes can be charged and discharged repeatedly without showing any visible degradation. 74/ Thus, this battery has the potential for long-life. 75/ In addition, its energy density remains high even under rapid discharge conditions. It has been projected that plastic batteries could have much higher power, much lower weight and require considerably less volume than conventional lead-acid batteries. 76/

A number of phylene-based polymers have also been made electrically conducting. One, polyphenylene, has the advantage of being considerably more stable than polyactylene when in the undoped state. Polyactylene's advantage is that

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74/ Dagani, Ron. Organic Battery Uses Polyacetylene Electrodes. Chemical and Engineering News, v. 59, Jan. 1981. p. 39.

75/ Knodt, Kenneth S. C&D Batteries Announces Plastic Battery Technology. Plymouth Meeting, Pennsylvania, C&D Batteries (News Release), Sept. 24, 1981. p. 3.

76/ Ibid., p. 1.

it can be made into very thin, flexible sheets with high surface areas, which are necessary for high power density. It is not yet clear which polymer will emerge first for commercial application. 77/

Potential applications include battery-powered hand tools, wristwatches, automobile starters and electric cars. 78/ Plastic batteries would be ideal for electric cars because of their high power and low weight. Since the conductive polymer technology could have about three times the energy density of its lead-acid counterpart (60 miles), it could provide a vehicle with as much as 180 miles of travel without a recharge. Plastic batteries may also find use as customer-side-of-the-meter energy storage for residential and commercial buildings, where they could be used to reduce peak demand for electricity. Additionally, because of their anticipated light weight, plastic batteries may be useful in portable communications applications. 79/

However, the doping of a conductive polymer makes its electrical properties susceptible to deterioration when it is exposed to air or moisture. Thus, plastic batteries have some problems involving efficiency and shelf life. Nevertheless, C&D Batteries (a subsidiary of Allied Chemical) is optimistic that these problems can be overcome by using the sealed-battery technology that is used in other high energy batteries. The company has committed $5 million to develop a plastic battery, and expects it to become available commercially within 5 to 10 years. 80/

77/ Ibid., p. 6.

78/ Knodt, p. 4.

79/ Ibid., p. 7.

80/ Ruby, Daniel. New Promise for the Electric Car: Plastic-Metal Batteries. Popular Science, v. 220, Feb. 1982. p. 136.

Fuel Cells

A fuel cell oxidizes hydrogen, usually obtained from water or a hydrocarbon fuel, and converts the liberated chemical energy directly into electricity. Unlike a battery, which undergoes a chemical change upon converting stored energy, a fuel cell depends on a hydrogen-rich gas supplied from outside the cell and undergoes no material change. The fuel is introduced at the negative electrode and reacts with an oxidizing agent (such as airborne oxygen) that is introduced at the positive electrode. This arrangement is illustrated in figure 7. The electrodes are immersed in an electrolyte that may be an acidic solution, an alkaline solution, a molten salt, or a solid. Depending on its makeup, a fuel cell may operate at room temperatures or it may require very high temperatures. 81/

The major attraction of a fuel cell is its ability to convert fuel into electricity at high efficiencies. The maximum theoretical efficiency of a fuel cell is 83 percent, and fuel cells with operating efficiencies higher than 50 percent have been fabricated. In contrast, the average efficiency of a conventional power plant is 35 percent. 82/ Additionally, fuel cells can be operated in a cogeneration mode by using the waste heat from heat exchangers and fuel gases for industrial process heat. 83/ Fuel cells are also modular, noiseless, and pose no immediate threats to air quality or other environmental concerns. However, the development

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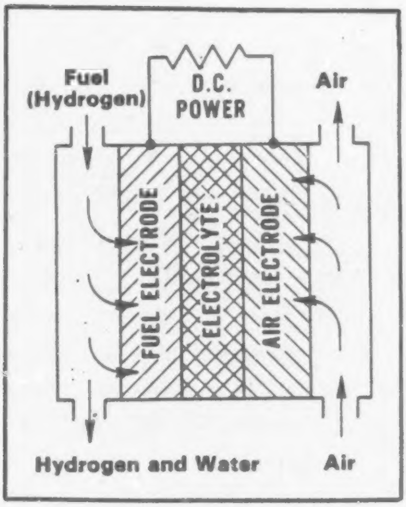
81/ Roberts, New Developments, p. 9.

82/ U.S. Congress. Joint Economic Committee. Pursuing Energy Supply Options: Cost Effective R&D Strategies. Joint Committee Print, 97th Cong., 1st Sess., Apr. 27, 1981. (Chapter on Fuel Cells by George Chatham) Washington, U.S. Govt. Print. Off., 1981. p. 271.

83/ Criner, Douglas E., et al. Fuel Cells--An Industrial Cogeneration Perspective. In Energy Technology VII, 1980. Edited by Richard F. Hill. Washington, Government Institutes, Inc. p. 983-991.

FIGURE 7: Fuel Cell


Fuel
(Hydrogen)
D.C.
POWER
Air
FUEL ELECTRODE
ELECTROLYTE
AIR ELECTRODE
Hydrogen and Water
Air

Source: Energy Daily, July 7, 1981. p. 2.

of less expensive electrodes with a longer operating life is a major concern for reducing fuel cell costs. 84/

Fuel cells can provide supplemental or standby capacity for generating power with siting possibilities and versatility not available to coal or nuclear powerplants. They can be used in utility, industrial/commercial, and residential sectors. Additionally, a combination of a fuel cell with a storage battery may provide the most feasible prospect for an electric/hybrid vehicle. 85/ Because fuel cells can convert hydrogen to electricity with high efficiencies, they may also play an important role in the development of hydrogen energy storage systems.

Phosphoric Acid Fuel Cell

This fuel cell has been proven through more than 15 years of fabrication and field test experience. It operates at about 390 degrees F. A 4.8 Megawatt phosphoric acid fuel cell is scheduled to begin operation in 1983. It is the most significant utility-scale demonstration of a fuel cell to date. 86/

A second 40 kilowatt phosphoric acid fuel cell is being demonstrated as an onsite/integrated energy system (OS/IES) for residential and commercial buildings. It is to be operated in a cogeneration mode in which rejected heat from the cell is recovered to provide space heating for apartment and office complexes. An assessment of the potential for this technology shows that it is not yet competitive with conventional utilities and other cogeneration technologies such as gas engines and turbines. Even with projected cost-reducing improvements and

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84/ Fuel Cells. In Energy Alternatives: Report of the Special Committee on Alternative Energy and Oil Substitution to the Parliament of Canada. Ottawa, Canada, Canadian Government Publishing Centre, 1981. p. 159.

85/ Roberts, New Developments, p. 12-13.

86/ Chatham, Fuel Cells, p. 272.

mass production, it is estimated that the multi-kilowatt OS/IES fuel cell will still cost three times more than available cogeneration technologies. This system may be limited to special applications which cannot be serviced by cogeneration options. These might include military, uninterrupted power supplies, d.c. power requirements, and variable frequency applications. 87/

Molten Carbonate Fuel Cell

This cell employs an electrolyte composed of lithium and potassium carbonate salts and small particles of lithium aluminate. At operating temperatures near 1200 degrees F, the carbonates melt but do not flow. A molten carbonate fuel cell integrated with a coal gasification powerplant is one of the most promising coal-using technologies because of its high efficiency, acceptable cost, and environmental acceptability. The high-temperature heat available from the fuel cell may be used in a bottoming cycle and/or an industrial cogeneration application. Because of its elevated operating temperature any solid, liquid, or gaseous hydrocarbon can be used. The laboratory-scale cells have surpassed 40,000 hours of life. A two kilowatt system is due to be tested during FY83. 88/

Polymer Fuel Cell

A solid polymer electrolyte fuel cell is being developed at the General Electric Company. This cell operates at 220 degrees F, occupies a small volume,

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87/ Orlando, J. A., et al. Analysis of Phosphoric Acid Fuel Cell Powerplants for OS/IES in Residential/Commercial Applications. Alexandria, Va., GKCO Consultants, Dec. 15, 1981. p. 1-3.

88/ Marianowski, Leonard G., and John B. O'Sullivan. Status of Molten Carbonate Fuel Cell Technology. In Energy Technology VIII, 1981. Edited by Richard F. Hill. Washington, Government Institutes, Inc. p. 1069-1086.

and has high energy and power densities. The cost is rather high because the cell employs Nafion, a polymer membrane made by DuPont which appears to be inherently expensive. Research is concentrated on finding a less expensive substitute for Nafion. The system was originally developed for water electrolysis, but is now being studied for electric vehicle and stationary electric storage applications. 89/

Alkaline Fuel Cell

The alkaline fuel cell received extensive study during the 1950s and 1960s. However, the sensitivity of its potassium hydroxide electrolyte to carbon monoxide and dioxide gases formed in the fuel processing operation has discouraged research on this approach. Alternatively, ammonia is being studied for use with this system since it can be broken down to yield hydrogen without the carbon gases. The alkaline fuel cell has many favorable performance characteristics and has the potential for low cost since it utilizes little, if any, platinum as a catalyst. It can be operated at room temperature, and is being considered for electric vehicle and stationary applications. 90/

Solar-Powered Fuel Cell Application

This system contains four components: solar energy collector, a fuel cell, and two storage vessels. The collector contains millions of tiny silicon spheres (crystals) immersed in a solution containing hydrogen bromide. The spheres and solution are embedded in a flat glass matrix. Doping of the

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89/ Personal communication, Meredith, DOE, Aug. 1982.

90/ Ibid.

silicon crystals turns each sphere into a diode, controlling its polarity and allowing it to serve as a tiny generator of electricity. When sunlight impinges on the spheres, they act like tiny batteries: Each sphere produces a minute electrical current, breaking down (electrolysing) the halogen acid into hydrogen gas and bromide liquid.

A solid hydride holds the hydrogen, while the bromine is stored as a liquid—along with the electrolyte—in a solution. The hydrogen and bromide are stored separately until needed, then recombined in a fuel cell to produce electrical energy. When the hydrogen and bromine recombine in the fuel cell, a fresh batch of electrolyte is formed for another cycle through the collector. Thus, aside from a small amount of heat and a little excess hydrogen gas, the system is completely self-contained: Sunlight goes in one end, and electricity comes out the other. 91/

Texas Instruments (TI) expects to achieve an overall system conversion efficiency of 6 percent by September 1982. Their eventual target is 8 to 10 percent. TI has spent $4 million and DOE has spent $12 million in a cooperative agreement to develop this technology. Commercial production is planned for the mid-1980s. 92/

PHYSICAL AND CHEMICAL STORAGE

The four major types of storage technology included in this category are: thermal, mechanical, hydrogen, and magnetic storage.

91/ U.S. DOE. Development of a Solar Energy System. (By E. L. Johnson). (DOE/ER/10000-T2) Apr. 3, 1981. 21 p.

92/ Poss, John G. Solar Batteries Planned for New Homes. High Technology, v. 2, July/Aug. 1982. p. 21-24.

Thermal Storage

Thermal energy storage (TES) involves technologies which accept and return energy in the form of heat. A device for thermal storage may become "hot" and serve as an energy source at the time of use, such as for space heating. TES also includes the accumulation of "cold" or "coolness," whereby the storage device becomes a thermal energy sink at the time of use. Typical examples of this use are air conditioning and refrigeration. 93/

Thermal energy obtained directly from renewable and waste heat sources or indirectly from the conversion of off-peak electricity can be stored on a daily or seasonal basis. It can be stored in any of three forms: sensible, latent, or thermochemical heat. Sensible heat storage involves the use of the thermal capacity of materials such as rocks and water to absorb and release heat. Latent heat involves the use of the ability of materials to absorb and release thermal energy when going through a change of phase—for example, water changing to steam. Thermochemical heat storage involves the use of low temperature environmental heat to drive chemical reactions which release heat at higher temperatures. Almost all commercial TES technologies use sensible heat storage. However, a variety of technical options based on the other forms are becoming available for storing thermal energy. Both the method of energy production or collection and the end-use application influence the choice of storage device. TES technologies are expected to have near- or mid-term impact on renewable energy supply continuity and electric utilities' peaking problems. TES also has potential for mid-term applications in the industrial sector. 94/

93/ Gahimer, John. An Overview of the DOE Thermal Storage Program. In Peak-Load Pricing and Thermal Energy Storage. Sponsored by U.S. DOE. Division of Energy Storage Systems. July 15-17, 1979. p. 94.

94/ DOE, Energy Storage Systems, p. III-3.

Sensible Heat Systems

The energy absorbed or released by a storage material as its temperature is increased or decreased is termed internal or sensible heat. The energy storage density of a sensible heat system is maximized by using a material with both a high density and high specific heat capacity and by operating the system over as large a temperature range as possible, consistent with material properties and other system constraints. 95/ Major disadvantages of sensible heat storage systems are that stored heat is generally returned at an ever-decreasing temperature level and storage densities are relatively low. 96/ As a result of the low densities, sensible heat storage tends to be bulky. Volume reductions obtained by using higher energy density media tend to be offset by the requirement for more expensive containers or heat exchangers. 97/ Advantages of sensible heat storage include low cost and simplicity. 98/

Short-term sensible heat storage. Common low temperature (less than 200 degrees F) sensible heat storage media include water, rock, sand, or Earth. Water tanks and rock beds are established, well understood systems. Water and gravel are attractive materials because of their very low cost and reasonably high energy density. 99/ Many conventional water and rock systems can be used with active or passive solar heating and cooling systems. 100/ The basis for

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95/ Aerospace Corporation, p. 2-62 to 2-63.

96/ Gahimer, p. 94.

97/ Baylin, Frank. Low Temperature Thermal Energy Storage. Golden, Colorado, Solar Energy Research Institute. (SERI/RR-54-164) July 1979. p. 1.

98/ Gahimer, p. 94.

99/ Aerospace, p. 2-63.

100/ DOE, Energy Storage Systems, p. III-8.

sensible heat technology is well understood except for the case of Earth storage. However, research is underway to improve understanding of how the arrangement of heat injection sites and variations in soil conductivity with moisture affect Earth storage efficiency. 101/

Liquid storage. Liquid storage media readily permit efficient convective transfer of heat because of convection currents set up by thermal gradients and are, thus, better suited than rocks for heat transfer. For the same reason, liquids are generally less suited for maintaining thermal stratification gradients. A solar pond is an exception; it employs a salt gradient to maintain thermal stratification. Liquids are more suited than rocks, earth, or sand to retrofit applications because of smaller storage volume requirements. Water has an additional advantage for applications such as industrial washing processes or residential hot water in that it is both storage medium and product. Conversely, liquids have disadvantages because of requirements for freeze protection in most climates. 102/

Rock storage. Rock storage is typically used with systems that employ air as a heat transfer medium. Air passes through the collectors and then through a rock bin, heating the rocks. Performance of the storage is affected by the shape, size, density, and specific heat of the rocks and by the design of the container. The advantages of using rocks as thermal storage material are: (1) there is excellent heat transfer because of the large surface area of the rocks; (2) because there is little contact between rocks, rock bins stratify effectively, thereby preventing the spread of heat and improving the collection

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101/ Personal communication with Dr. Imre Gyuk, DOE Energy Storage Program, Dec. 7, 1982.

102/ Baylin, Low Temperature Storage, p. 4.

efficiency of the system; and (3) rocks neither freeze nor boil. The disadvantages are: (1) rocks occupy three times as much volume as an amount of water with the same thermal capacitance; (2) condensation, dust, mildew, and vermin cause problems since it is difficult or impossible to service a rock bin; (3) leakage may be a problem; and (4) radon release may be significant. 103/

Application to load management. Sensible storage of electrically-produced heat can be effective for utility load management. Often referred to as "customer-side-of-the-meter" storage, its primary use is for space heating and domestic water heating. Electric storage heating employs resistively heated ceramics or refractory bricks to store energy during off-peak hours for space heating during peak hours of electric demand. Storage water heating systems employ off-peak power to heat water stored in tanks at user sites. These systems are useful where utilities have winter peaks, and they have been commercialized in some areas of Europe. 104/

Seasonal sensible heat storage. The source or sources of heat or cold for an energy supply system may be subject to daily or seasonal variations, as is the case with solar energy and summer-peaking of cogenerated electricity and heat. Additionally, the demand for energy may be seasonal, as is the case with space heating, air conditioning, and food processing. The purpose of seasonal sensible heat storage is to even out long-term variations in energy production and/or use. 105/ Applications of seasonal sensible heat storage systems

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103/ National Research Council. Committee on Advanced Energy Storage Systems. Energy Storage for Solar Applications. Washington, National Academy Press, 1981. p. 34.

104/ DOE, Peak-Load Pricing and Thermal Energy Storage.

105/ DOE, Energy Storage Systems, p. III-4.

include hot water production, district heating and cooling, industrial process heat, crop drying, and mechanical and electric power production.

Two examples of solar heat use can illustrate the advantages of seasonal sensible heat storage. One, the lack of daily solar insolation at the higher latitudes during the winter may be compensated in the summer. That is, daily solar conversion may not be sufficient during the winter, but the use of seasonal sensible heat storage may make it reasonable to collect summer radiation for use in winter. Additionally, since seasonal sensible heat storage systems are not sensitive to short-term weather variations, they might substantially reduce the size of the solar collector system needed for a given application. If storage system costs are less than collector costs, then the total cost of the solar energy supply would be reduced. This type of seasonal storage may also make it possible for solar energy to provide 100 percent of the heating and/or cooling requirements for a building. 106/ Three basic types of seasonal systems are being investigated: large tanks and beds, aquifers, and solar ponds.

Large storage tanks and beds. These devices differ from smaller scale, short-term units only in construction details. In retrofit applications, space is a limiting consideration. However, in new construction, such devices can be built underneath or adjacent to structures. 107/

District heating provides a possible application of seasonal energy storage in large steel tanks. In one current application, the heat source is

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106/ Baylin, p. 1.

107/ Ibid., p. 4.

an aluminum processing plant. 108/ Waste heat, in the form of hot flue gases, is ejected from the plant and used to supply input for a heat exchanger which provides hot water. Since aluminum production is a continuous process, the recoverable waste heat is produced at a constant rate on a daily and yearly basis. However, the energy requirements of a district heating system vary widely on both a daily and seasonal basis. 109/ The energy recovered from the plant can provide 32.5 Megawatts-thermal (MWt) of hot water to the system, which is designed to supply a peak load of 45 MWt. Thus, a seasonal hot water thermal storage system was designed to supply the additional 12.5 MWt. When the heating demand is less than 32.5 MWt, the excess energy is stored for future use when the load is higher. The necessary storage capacity is supplied by eight above-ground, insulated steel tanks, each of which can hold 25 million gallons of water. 110/

Aquifers. Aquifers are large, underground, porous sand and rock formations which contain large quantities of water. An aquifer is pictured in figure 8. Aquifers occur naturally, at depths ranging from a few feet to several miles. They are insulated by caprock and bedrock materials which have low thermal conductivities. Given the right conditions, aquifers can store very large amounts of hot or cold water for long periods of time and at low cost. The use of an aquifer for seasonal heating involves the input of solar heat or waste heat from utility or industrial sources for subsequent use in heating

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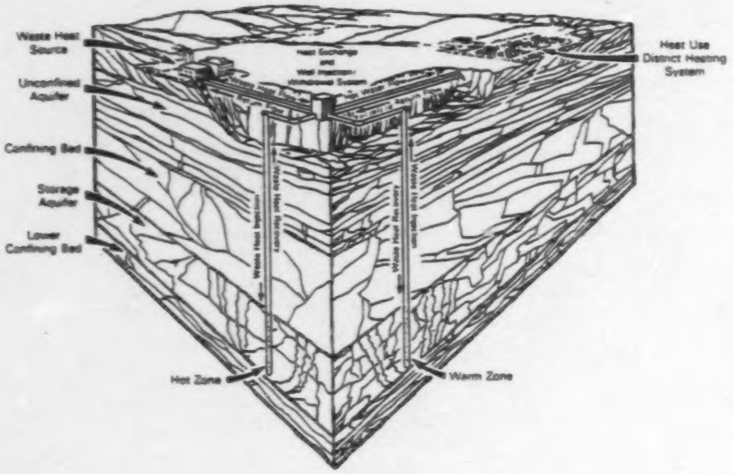
108/ Oliker, Ishai, and Mitchell Olszewski. Once-Through Heat Transport and Seasonal Storage for City of Bellingham. District Heating, v. 67, 1st Quarter 1982. p. 5-12.

109/ Kattar, Lincoln B., and Randel L. Hoskins. Applications of Thermal Energy Storage to Process Heat and Waste Heat Recovery in the Primary Aluminum Industry. U.S. DOE. Apr. 1979. (CONS-5080-1) p. 32.

110/ Oliker and Olszewski.

FIGURE 8: Aquifer Seasonal Storage for District Heating


Waste Heat Source
Unconfined Aquifer
Confining Bed
Storage Aquifer
Lower Confining Bed
Heat Exchange and Well Injection Withdrawal System
Heat Use District Heating System
Waste Heat Injection
Waste Heat Recovery
Hot Zone
Warm Zone

Source: Gahiner, J.S., et al. DOE Thermal Energy Storage Program Overview, 1979.

buildings. It is capable of storing hot water under pressure at temperatures up to 400 degrees F. Thus, it is especially attractive for large scale applications such as cogeneration and district heating. 111/

Over a 3-month period, thermal storage efficiencies of 68 percent have been demonstrated with low temperature (120 degrees F) hot water. Studies suggest that after repeated cycles, heating of the containing bedrock may raise the efficiencies as high as 80 percent. 112/ Although there have been no demonstrations yet, storage efficiencies for high temperature water (210 degrees F) are expected to be somewhat lower because of heat spreading due to buoyancy. However, some researchers expect that changes in the siting of injection points may reduce this problem and make possible higher efficiencies for both low and high temperature water. 113/

Aquifers can also be used to store winter chilled water for summer air conditioning. This technique involves pumping water from one well of an aquifer, chilling it in a cooling tower and injecting it in a second well. In most of the United States, winter air temperatures are low enough to chill the water. In summer, the cold water can be withdrawn and used for air conditioning. China has a 15-year history of chilled water storage in aquifers. Starting in Shanghai during 1965, the technique is now used in over 10 Chinese cities. In Shanghai alone, over 100 million "tons" of chilled water have been injected into aquifers between 1965 and 1979. In a typical Chinese system,

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111/ Gyuk, Imre. Thermal Energy Storage in Aquifers—Report on a Seminar. District Heating, v. 67, 1st Quarter, 1982. p. 130.

112/ Baylin. Low Temperature Storage, p. 5.

113/ Personal communication with Dr. Imre Gyuk, DOE, Energy Storage Program. Dec. 7, 1982.

water is injected at temperatures from 33 to 51 degrees F by gravity or pumping. At extraction in summer, the temperatures vary from 46 to 53 degrees F. 114/

The major capital cost of aquifer thermal energy storage involves the digging of wells for water extraction and return. 115/ The cost of system development has been estimated to be about $55,000 per Megawatt-thermal (MWt). Technical concerns involve chemical and geological aspects of the aquifer. Geochemical reactions can lead to the clogging of wells and the precipation of salts in the connecting pipes. Additionally, the fracture of a hot water aquifer could cause serious heat pollution problems. 116/ Federal support for a planned multimillion dollar series of field demonstrations of aquifer thermal energy storage was recently curtailed. 117/

Solar ponds. A solar salt-gradient pond is a body of water that collects solar radiation and stores it as heated water near the bottom of the pond. This arrangement is illustrated in figure 9. The salt concentration of the water is higher near the bottom, which increases the relative density of the heated water and prevents its convection toward the surface. Thus, the pond contains one uniform-density convective layer for heat storage and another overlying gradient layer for insulation. Heat is removed from the top of the convective layer by either a submerged heat exchanger or by extraction of hot saline solution from the pond for external heat exchange. 118/

114/ Gyuk, Imre. Winter Chill Storage in Aquifers. District Heating, v. 67, 2d Quarter, 1982. p. 7.

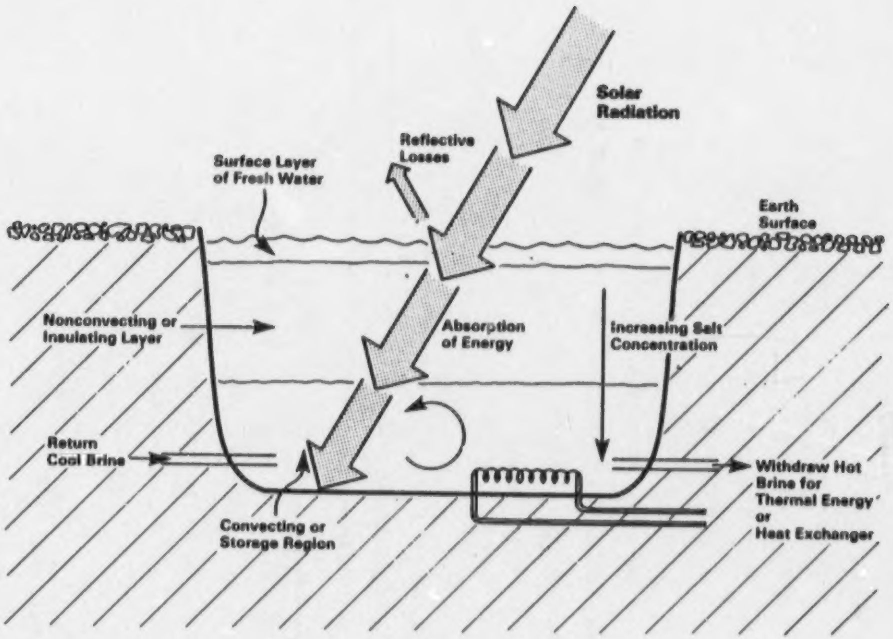
115/ Baylin, p. 5.

116/ Ibid.

117/ Meyer, Overview of Seasonal Storage, p. 28.

118/ Baylin, Low Temperature Storage, p. 6

FIGURE 9: Salt Gradient Solar Pond



Solar Radiation
Reflective Losses
Surface Layer of Fresh Water
Earth Surface
Nonconvecting or Insulating Layer
Absorption of Energy
Increasing Salt Concentration
Return Cool Brine
Withdraw Hot Brine for Thermal Energy or Heat Exchanger
Convecting or Storage Region

Source: Baylin, Low Temperature Storage, p. 7.

A solar pond stores heat at temperatures up to 212 degrees F, with operational temperatures in the 120 to 190 degrees F range. Although the system efficiency is low (10 to 30 percent) because of the low temperatures involved, the pond has the ability to provide a large amount of low-temperature heat that is insensitive to daily and seasonal fluctuations in insolation and air temperature. This latter feature enables it to maintain its operational temperatures for up to 5 months, which makes it suitable for winter. 119/

Estimates of solar pond construction costs range from $0.60 to $6.00 per million BTU (MBtu). 120/ For the district heating application, minimum energy costs have been projected to be 6 cents/KWh. 121/ Land requirements limit markets to rural and suburban areas. Some estimates of potential contribution to U.S. energy supply range as high as 6 quads. 122/

There are two areas of concern regarding salt control: maintenance of the insulating gradient layer and loss of brine into the soil. 123/ Although gradient stability is virtually assured when salt concentration is high, the cost of salt is also increased and the possibility of environmental problems is accentuated. Instability can be triggered by strong winds, heating of pond walls, and rapid night cooling of the surface layer. 124/ A cover has not yet

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119/ Jayadev, T. S., and M. Edesess. Solar Ponds and Their Applications. In Energy Technology VII, 1980. Edited by Richard F. Hill. Washington, Government Institutes, Inc. p. 1191.

120/ Neeper, D. A., and K. A. Meyer. Solar Ponds as a Source of Low Temperature Heat. In Energy Technology VIII, 1981. Edited by Richard F. Hill.

121/ Leboeuf, Application of Solar Ponds, p. 31.

122/ Jayadev, Solar Ponds, p. 1193.

123/ Neeper, p. 1217.

124/ Baylin, p. 6.

been designed which insulates ponds from such instabilities, and will also: (1) let sufficient sunlight through, (2) be of adequate strength to resist tearing, and (3) be of low enough cost to enable the pond concept to remain economical. 125/

Latent Heat (Phase Change) Systems

When a material undergoes a phase change (such as melting, evaporation, or change in crystalline form), heat is absorbed or released and the temperature of the material remains constant until the change is completed. The change in heat content per unit mass of material is termed the latent heat of phase change. Phase change materials can offer a larger heat capacity over a limited temperature range than sensible heat systems and can supply heat at a constant temperature. 126/ Consequently, application of latent heat energy storage systems is usually designed to operate in a narrow temperature range around the phase-change temperature. 127/

The evaluation of a substance as a phase change material is more complex than a similar evaluation for use in a sensible heat system. Candidate materials must be readily available, inexpensive, safe, minimally corrosive, and have a high heat of fusion. It is also desirable to have a reasonably small volume change and low vapor pressure over the useful range of temperatures so no undue stress is placed on storage containers. 128/

125/ Personal communication with Dr. Imre Gyuk, DOE Energy Storage Program, Dec. 10, 1982.

126/ Jensen, Johannes. Energy Storage. Woburn, Mass., Butterworths, 1980. p. 20.

127/ Aerospace Corporation, p. 2-66.

128/ Baylin, p. 8.

Short term latent heat storage. The development of latent heat storage for short-term applications is focused on using the phase change properties of salt hydrates and organic compounds.

Salt hydrates. The solid-liquid transformation of salt hydrates is actually a dehydration or hydration of the salt, although this process resembles melting or freezing thermodynamically. Some salt hydrates do not dissolve completely when undergoing the "melting" transformation.

The most difficult problem for salt hydrates is salt settling: material segregation during the melting process. Following melting, the insoluble portion of salt tends to settle and remain at the bottom of the container. Within a few freezing/melting cycles, significant amounts of salt accumulate at the bottom of the container. In subsequent cycles this material will not hydrate effectively and, thus, may seriously impair performance. Another problem is that salt hydrates may cool below their normal freezing points without solidifying. This behavior interferes with normal functioning of the storage system. Additionally, corrosion of the container or water losses can introduce further difficulties. 129/

Organic compounds. Organic compounds of lower molecular weight are theoretically the most promising phase change materials for use in thermal storage systems because of their high transition energies. However, many such substances are unstable, costly, highly flammable, or fall outside the desired temperature range. Paraffins are the most attractive because they are relatively inexpensive and safe and have reasonably high heats of transition compared to

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129/ Baylin, Low Temperature Storage, p. 10.

other organic compounds. The least expensive waxes melt over a range of temperatures from 115 to 118 degrees F, but cost more than 16 cents per pound, which is high compared to salt hydrates.

Because all of these substances are completely soluble at their melting temperature, the only major limitation to performance is heat transfer across a solid boundary. The high cost of the material is the main limitation, but in addition, storage devices using paraffin incur costs associated with containers and heat transfer methods, especially since the heat transfer within paraffin is relatively low. 130/

Seasonal Latent Heat Storage. Water to ice phase changes can be used to supply thermal storage on a seasonal basis. Water is a good candidate for use as a latent heat storage medium in space cooling applications since it is safe and inexpensive. There are two basic types of water/ice energy storage systems under examination: heat pump (annual cycle) and ice pond systems. 131/ Seasonal latent heat storage is of interest for utility load-leveling applications and for increasing the usefulness of renewable energy systems.

Heat pump (annual cycle) storage. In a heat pump system, the heat of fusion of water stored in an insulated underground tank is available as a heat source in winter and as a heat sink in summer. As the pump extracts heat during the winter season, most of the water is frozen, and the stored ice provides air conditioning in the summer. Two ice-formation methods can be used. One, the brine-chiller, utilizes chilled brine to freeze the water surrounding heat-exchanger coils immersed in the storage bin. The other, the ice maker, forms

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130/ Baylin, p. 11.

131/ Ibid.

ice directly on the evaporator plates of the heat pump, and the ice is periodically harvested into the bin. This arrangement is illustrated in figure 10. The advantages of the brine-chiller are smaller bins, simpler refrigeration circuitry, and a nonfreezing energy transfer medium (the brine) which can accommodate supplementary sources such as solar panels. The advantages of the ice maker are the elimination of the ice bin coil and easier modularization of the system by manufacturers. 132/

In actual application, the operation of the heat pump system will seldom, if ever, result in the production of the exact amount of ice needed for air conditioning. Thus, provisions must be made for melting excess ice and for supplemental air conditioning when ice deficits exist. This can be accomplished by use of a solar collector panel that collects heat from the environment during the winter season to melt excess ice and by heat pump operation at night during the summer season to produce chilled water or ice for supplemental air conditioning. 133/

Ice ponds. An ice pond is constructed by operating a special spray nozzle that ejects small drops of water into cold winter air, which converts the droplets into ice particles. The ice is accumulated in an insulated ground pit. In the summer, air from the building is used in a heat exchanger to heat water which, in turn, is used to melt ice, making water at about 45 degrees F. This water is drawn off from the bottom of the pit and pumped indoors where it is used in the heat exchanger to cool air. A pond containing 100 tons

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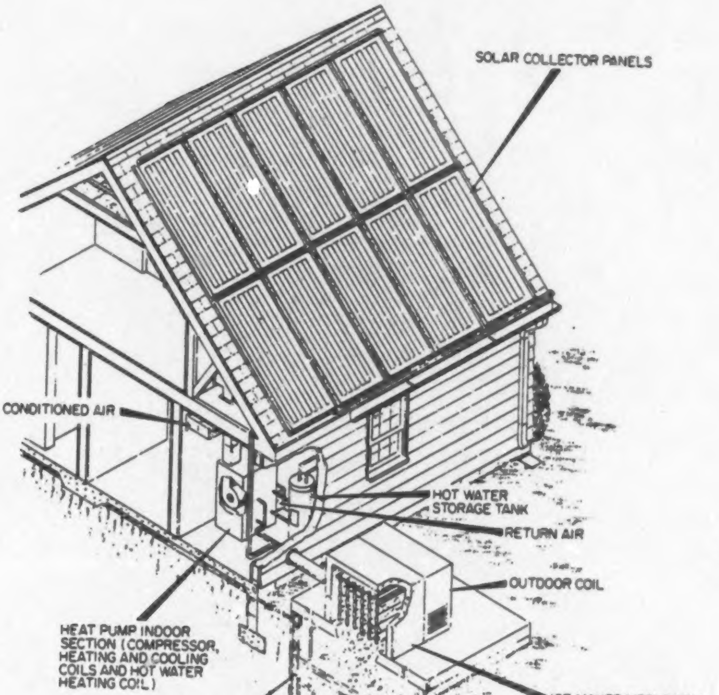
132/ Nephew, E. A., et al. Theory and Design of An Annual Cycle Energy System (ACES) for Residences. U.S. DOE. Oak Ridge National Laboratory. (ORNL/CON-43) Oak Ridge, Tenn., May 1980. p. 1-2.

133/ Ibid., p. 2.

FIGURE 10: Ice-Maker/Heat Pump Storage for Residences


SOLAR COLLECTOR PANELS
CONDITIONED AIR
HOT WATER STORAGE TANK
RETURN AIR
OUTDOOR COIL
HEAT PUMP INDOOR SECTION (COMPRESSOR, HEATING AND COOLING COILS AND HOT WATER HEATING COIL)
ICE MAKER MECHANISM (INSULATED ENCLOSURE)
WATER TIGHT INSULATED BIN

Source: Nephew, E.A., et al. Theory and Design of an Annual Cycle Energy System (ACES). [ORNL/CON-43] May 1980. p. 26.

(about 27,000 cubic feet) of ice appears to be adequate for cooling a single house from spring to fall. 134/ However, the capacity to accumulate this amount of ice may be limited by geography or climate. The electricity that drives the snow machine amounts to a small fraction of the electricity that is saved by the cooling capacity of the ice. 135/

Containment. There are three techniques being used to contain phase change materials: bulk, macroencapsulation, and building materials. Bulk containment refers to enclosure within large containers with heat exchange effected by coils immersed within the material. In macroencapsulation, the material is packaged in a nonpermeable membrane that also functions as a heat exchange surface. Building materials can provide both structural support and thermal storage capacity. 136/ Bulk containment methods are being used with phase-change materials being developed for resistance heating in customer-side-of-the-meter storage applications. Macroencapsulation and building materials are being used in conjunction with the development of phase-materials for both active and passive solar-thermal applications. 137/

Thermochemical Heat (Chemical Heat Pump) Systems

Thermal energy can be stored for indefinite periods of time by reversible chemical reactions. The chemical heat pump is a technology which uses such reactions to accomplish low temperature thermal energy storage. This technology

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134/ One ton of ice melting in a 24-hour period is equivalent to 12,000 Btu/hour of air conditioning load.

135/ McPhee, John. Ice Pond. New Yorker, v. 57, July 13, 1981. p. 92-95.

136/ Baylin, Low Temperature Storage, p. 12.

137/ Personal communication with Dr. Imre Gyuk, DOE Energy Storage Program, Dec. 10, 1982.

is illustrated in figure 11. The heat pump is made up of two interconnected vessels, each of which contains either a liquid or a solid. Thermal energy from a solar collector, utility waste heat, or any other low temperature source is input to the heat pump, which upgrades the heat from a relatively low temperature to a higher one. This high temperature heat is used to drive a heat-absorbing chemical reaction in one vessel. One of the reaction products moves in vapor or gaseous form to the other vessel of the pump. The energy absorbed can be released later by the reverse, heat-liberating reaction between the products.

When energy is required from storage, outside ambient temperature heat aids in driving the lower temperature reaction in the second container. The product of this low temperature reaction moves back into the first container where the heat-liberating reaction occurs. This pumping of heat is maximized by choosing optimal temperatures of reactions and optimal vessel pressures. In addition, the higher the heat of vaporization the more effectively heat can be stored and pumped to the load. 138/

To be suitable for use in a chemical heat pump, reactants must be minimally corrosive, inexpensive, stable and safe. Chemicals must be chosen such that operating temperatures and pressures are suitable for the heat input temperatures and ambient thermal source temperatures. Six systems are presently being developed: ammoniated salts, hydrated salts, methanolated salts, dilute/concentrated sulfuric acid, hydrated zeolites, and hydrogenated metals.

Chemical heat pump storage systems have two distinct advantages over other low temperature thermal storage systems. One, energy storage density is generally

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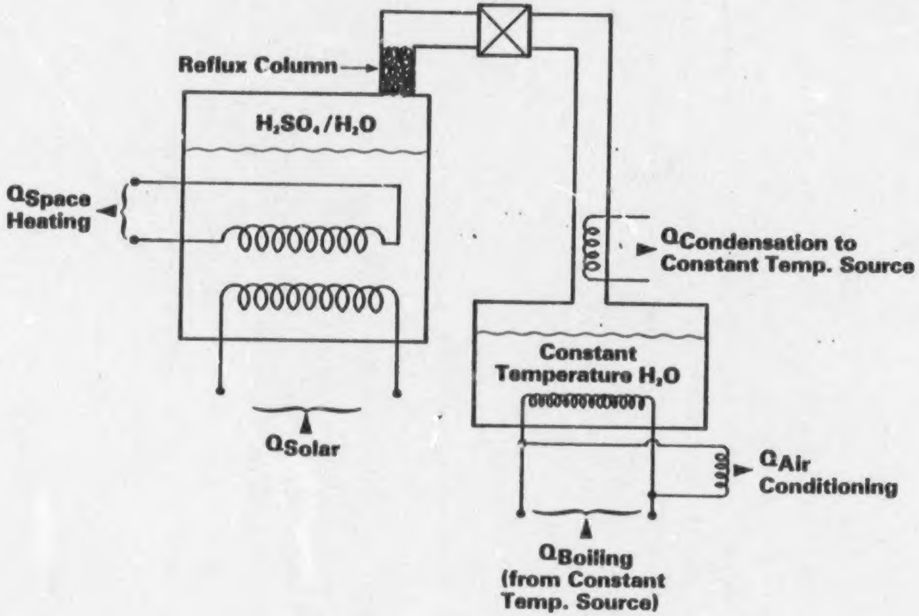
138/ Baylin, p. 13.

FIGURE 11: Sulfuric Acid Chemical Heat Pump


Reflux Column
H_2SO_4/H_2O
$Q_{Space\ Heating}$
Q_{Solar}
$Q_{Condensation\ to\ Constant\ Temp.\ Source}$
Constant Temperature H_2O
$Q_{Air\ Conditioning}$
$Q_{Boiling}$ (from Constant Temp. Source)

Source: Baylin, Low Temperature Storage, p. 93.

higher than for sensible heat or phase change material devices. Also, thermal energy can be stored at ambient temperatures allowing indefinite storage in situ or transportation with minimal thermal losses. However, three developmental problems for chemical heat pumps remain to be solved. One, the process must show that it is repeatedly reversible with minimal degradation of the reactants by side reactions. Also, corrosion must be minimized. Finally, adequate energy storage densities and efficiencies must be demonstated in cost-effective systems having acceptable heat transfer rates. 139/

Mechanical Storage

There are two basic types of mechanical storage technologies: flywheels and large-scale underground energy storage. Flywheels provide load-leveling to improve energy efficiency in conventional, electric and hybrid vehicles. They may also provide effective storage for solar technologies and for utilities through customer-side-of-the-meter storage. 140/ In the absence of effective customer-side-of-the-meter storage, large-scale energy storage allows a utility to use supply management to achieve a relatively stable load on its large units.

Large-scale energy storage has traditionally been provided by surface hydroelectric pumped storage plants. However, few natural sites for these systems are now available, and the construction of man-made sites is limited by environmental concerns. Thus, utilities are now considering underground pumped hydro (UPH) and compressed air energy storage (CAES) as alternatives. One underground CAES system in West Germany has operated effectively since 1978. While no UPH plant has yet been constructed, there is little concern about its feasibility since the hydraulic

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139/ Ibid., p. 16.

140/ DOE, Energy Storage Systems, p. III-17.

system involved is based on proven designs. There are four criteria for using underground systems: (1) a low load factor or large variance in daily loads, (2) available coal or nuclear baseload pumping power, (3) a need for new generation capacity, and (4) an acceptably deep, nearby underground geologic formation. 141/

The major advantages of mechanical energy storage devices are their relatively high efficiency and their capability of transferring energy rapidly into and out of storage. The latter quality allows these systems to improve utility system reliability by increasing the capacity to respond to sudden load changes. 142/ The major disadvantage of mechanical energy storage devices is their relatively low energy density and thus their high weight and cost for storing large amounts of energy.

Flywheels

Energy is stored in a flywheel as inertial kinetic energy of rotation. The storage capability of a flywheel depends primarily on the mechanical properties of the materials from which its rotor is fabricated. Some examples of flywheels are illustrated in figure 12. The cost of flywheel materials and their fabrication are relatively high resulting in unit energy storage costs of $300 to $400 per kWh for rotors made of composite materials. 143/

There has been considerable work done on evaluating the potential of flywheels for energy storage applications in transportation and electric utility

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141/ Electric Power Research Institute (EPRI). Preliminary Design Study of Underground Pumped Hydro and Compressed-Air Energy Storage in Hard Rock, v.1, Executive Summary. (EPRI EM-1589 and DOE/ET 5047-1). Palo Alto, Calif., May 1981. p. 1-5 to 1-7.

142/ EPRI, Preliminary Design Study, p. 1-1 to 1-2.

143/ Aerospace Corporation, p. 2-2 to 2-5.

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FIGURE 12: Flywheels

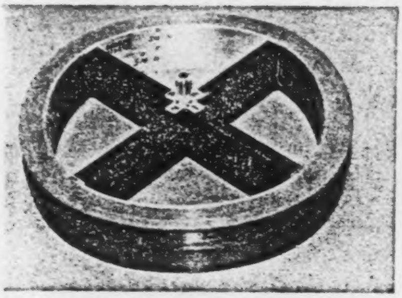

Fig. 1. Garrett AiResearch's multi-material—multi-ring rim rotor design with graphite/epoxy cruciform hub.

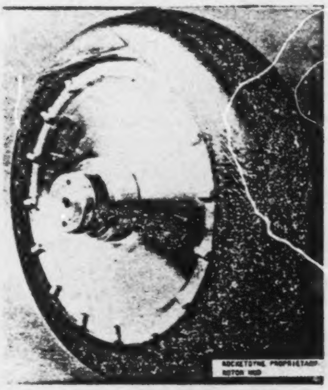

Fig. 2. Rocketdyne's multi-material-rim composite flywheel with twin-disk hub.

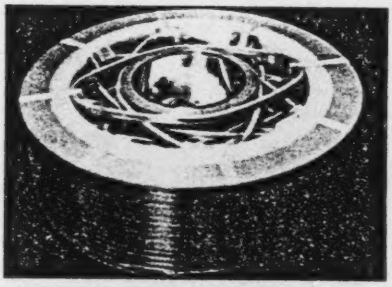

Fig. 3. Brobeck's multi-material-rim/tension-balanced-spoke rotor design.

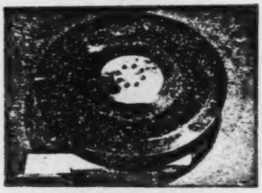

Fig. 4. Hercules' graphite /epoxy contoured, filament-wound flywheel assembly.

Source: Kulkami, Satish V. Flywheel Rotor and Containment Technology Development Program of the U.S. Dept. of Energy. (UCRL-84713), Lawrence Livermore Laboratory. Aug. 6, 1980.

load leveling. In transportation, flywheels are used to store and recover the energy of motion otherwise lost in breaking a vehicle. Flywheels may be considered as a major source of vehicle propulsion for certain vehicles, such as buses and trolleys, which make frequent stops. However, research on flywheels is focused primarily on its use as an energy conservation mechanism in conjunction with automobiles powered by a heat engine or battery. 144/ Utility applications of flywheels are no longer being pursued. 145/

Surface Pumped Hydro

This approach involves the storage of energy by using electricity to pump water from a reservoir at low elevation to one at a higher elevation during periods when there is an excess electrical generating capacity. When electrical demand exceeds the generating capability, the water operates a turbogenerator as it is returned to the lower elevation. The energy stored is related to the volume of water interchanged and the difference in elevation between the reservoirs. 146/

Pumped-hydro storage is presently well accepted by utilities as a cost-effective approach to load leveling. As of December 31, 1975, the electric power industry had a pumped storage capacity of nearly 10,000 MW and planned to add another 13,000 MW by 1986. 147/ All of the facilities presently in

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144/ Gyuk, DOE Energy Storage Program, Dec. 6, 1982.

145/ Personal communication with James Swisher, DOE Energy Storage Program, July 27, 1982.

146/ Aerospace Corporation, p. 2-227.

147/ Ibid., p. 2-228.

operation use surface reservoirs, but environmental siting restrictions make it increasingly difficult to continue using them. Some of the planned facilities would use underground reservoirs. 148/

Underground Pumped Hydro

The two reservoirs used in a pumped hydro arrangement can both be located at the surface, or the upper one can be at the surface and the lower one underground, or they can both be located underground. The latter two arrangements are referred to as underground pumped-hydro. The upper reservoir is almost always a lake, either natural or man-made. The lower reservoir can be an underground cavern (natural or excavated) or an aquifer. This arrangement is illustrated in figure 13. Elevation differences can range from several hundred to several thousand feet. The greater the elevation difference, the smaller the reservoirs required to store a given quantity of energy. Potential sites for both surface and underground configurations are almost uniformly distributed across the country. 149/

The arrangements for hydraulic and electrical equipment can be of two basic types. One of these is the tandem type with a separate pump and turbine on a common shaft, utilizing the same generator or motor. The other type of equipment is referred to as a reversible pump/turbine. In this arrangement, the turbine operates as a pump when driven in the reverse rotation. Variations of the reversible equipment are being designed for elevation differences in

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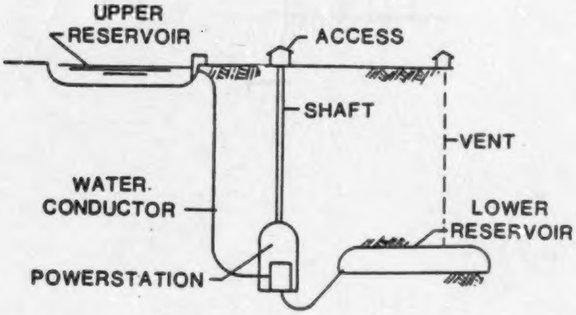
148/ Kalhammer, Energy-Storage Systems, p. 57.

149/ Aerospace, p. 2-228.

CRS-67

FIGURE 13: Underground Pumped Hydro Storage


UPPER
RESERVOIR
ACCESS
SHAFT
VENT
WATER
CONDUCTOR
LOWER
RESERVOIR
POWERSTATION

Source: The Aerospace Corporation. Characterization and Analysis of Energy Storage Systems. [ATR-77 (7538)-1] Dec. 1977. p. 2-231.

excess of 2,500 feet. These units may be particularly useful for applications in conjunction with underground reservoirs. 150/

Unless surface reservoirs, natural caverns or aquifers are available, the major cost is the excavation of an underground reservoir. The lifetime of equipment for a pumped-hydro facility is usually expected to be at least 25 to 30 years—much the same as that for a conventional hydroelectric plant.

The most serious environmental concerns for underground pumped-hydro storage systems (UPH) are the contamination and alteration of groundwater flow regimes. In the event of accidental drainage of the upper and lower reservoirs the underground powerhouse can become flooded, and worker safety considerations arise. A Federal Power Commission license is required to operate a UPH facility, and this entails the submission of an environmental impact statement. 151/

Underground Compressed Air Energy Storage

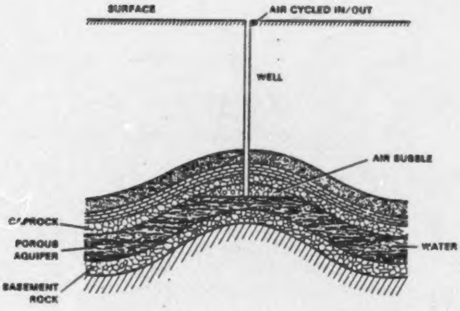
This technique can store energy by using electricity to pump air at high pressure into an underground reservoir—an aquifer, salt cavity or hardrock cavern—during periods of excess generating capacity. The compressed air arrangement is illustrated in figure 14. When demand exceeds the capacity of the baseload plant, the compressed air is combined with petroleum fuel and used to drive a gas turbine. Electricity is generated by coupling the gas turbine to a generator in much the same way conventional combustion turbine peaking plants operate. However, consumption of petroleum fuel is reduced by more than 60 percent.

150/ Ibid., p. 2-228 to 2-230.

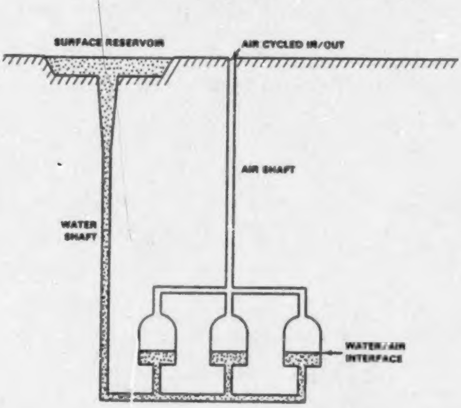
151/ Chiu, H. H., et al. Mechanical Energy Storage Systems: Compressed Air and Underground Pumped Hydro. Journal of Energy, v. 3, May-June 1979. p. 124.

FIGURE 14: Compressed Air Storage

Aquifer Air Storage System


SURFACE
AIR CYCLED IN/OUT
WELL
AIR BUBBLE
CAPROCK
POROUS AQUIFER
WATER
BASEMENT ROCK

Water-Compensated Hard Rock Cavern CAES System


SURFACE RESERVOIR
AIR CYCLED IN/OUT
AIR SHAFT
WATER SHAFT
WATER/AIR INTERFACE

Source: DOE Compressed Air Energy Storage. (Booklet). 1981.

Nevertheless, the problems of oil and gas availability have been identified as a major concern of utilities for implementation. Some advanced compressed air concepts are based on integration with fluidized bed combustion, coal gasifiers, and other techniques which would not require petroleum fuels at all. 152/

The major application of compressed air energy storage (CAES) is for electric utility load leveling. As with pumped hydro storage, it may also be used for intermediate and peak loads and spinning reserve. CAES could also be used in conjunction with a wind power system with the wind turbine driving the compressor directly. 153/

Electric utilities have become increasingly interested in compressed air storage as an alternative to pumped-hydro, which often presents facility siting problems. High pressure CAES require much smaller underground reservoirs and compensating ponds than pumped-hydro systems of comparable energy storage capacity. Also, the air reservoirs do not need to be as deep as the water reservoirs. Thus, there are likely to be more suitable sites for compressed air than for pumped-hydro. Additionally, since it is practical to plan smaller compressed air facilites than is cost-effective for pumped hydro, smaller initial capital investments are required. 154/

For large (1,000 to 10,000 MWH) storage facilities, the cost of system development for 10 hours storage is expected to range from $20 to $30 per kWH. The lifetime of a CAES facility is expected to be 25 to 30 years, much the same

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152/ Loscutoff, W. V., and L. D. Kannberg. Compressed Air Energy Storage Program Overview. U.S. DOE. Proceedings of Mechanical, Magnetic, and Underground Energy Storage 1980 Annual Contractors' Review. (CONF-801128) p. 126-127.

153/ Aerospace, p. 2-241.

154/ Ibid., p. 2-243.

as conventional combustion turbine peaking plants. 155/ However, the durability of the exhaust heat recuperator, which is not used in conventional peaking plants, is a major technical concern for CAES plants. For rock cavern CAES, there is an additional problem of flow instability in the water shaft. 156/

A well designed CAES plant should have a smaller impact on the environment than either a conventional peaking plant or a pumped-hydro facility. 157/ However, the site-specific nature of CAES could limit or prevent implementation. Environmental concerns such as reservoir material carryover, groundwater movement, or removal of excavated material may also pose problems. 158/

Compressed Air Demonstrations

A 290 MW CAES plant using salt dome caverns has been providing peak-leveling duty in Huntorf, West Germany since 1978. The success of this plant has provided a major impetus for efforts to commercialize a similar system in the United States. The Soyland Power Cooperative of Illinois is constructing the Nation's first CAES plant. It will be a 220 MW facility, operated in conjunction with a 600 MW coal-fired baseload powerplant. This plant, the second commercial plant worldwide, will use a hard-rock cavern with water-compensated constant-pressure storage. It will provide 11 hours of storage, cost about $156 million to build and is expected to begin operation by 1986. 159/ The addition of an exhaust-gas

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155/ Aerospace, p. 2-243 to 2-258.

156/ Kalhammar, Fritz. Compressed-Air Energy Storage. EPRI Journal, v. 6, May 1981.

157/ Loscutoff and Konnberg, Compressed Air Program, p. 126

158/ Chiu, Mechanical Storage, p. 133-134.

159/ Compressed-Air Power. EPRI Journal, v. 7, June 1982. p. 37-38.

recuperator in the plant design is expected to improve fuel-use efficiency by 33 percent in comparison with the Huntsdorf facility. Soyland Power will finance front-end studies and designs through a loan guarantee from the Department of Agriculture's Rural Electrification Administration. 160/

In fiscal years 1980 and 1981, DOE support for CAES research amounted to about half of the $9.1 million and $9.0 million allocated for all research on underground energy storage. DOE support for CAES dropped to $1.4 million during FY82. The Electric Power Research Institute (EPRI) spends $1 million to $2 million for CAES R&D per year. However, EPRI does not expect to continue all of the development efforts dropped due to declining Federal support. 161/ Nevertheless, EPRI is taking over management of Soyland project from DOE. 162/

Hydrogen Storage

Hydrogen is attractive as both an energy storage medium and as an long distance energy transport medium. However, difficulties with the containment of hydrogen in metallic tanks and pipelines has prompted research on new techniques for hydrogen storage. In addition, the production of hydrogen has been dependent primarily on the use of oil and natural gas (both as an energy source and as the feed material). Thus, R&D has also focused on new methods for producing hydrogen from alternate energy sources. 163/

160/ Federal R&D for Compressed-Air Energy Storage Wants, But United States May Have Its First Plant by 1986. Energy Research Reports, v. 7, Oct. 5, 1981. p. 4-5.

161/ Ibid., p. 2.

162/ Personal communication with James Swisher, DOE Energy Storage Program, July 27, 1982.

163/ U.S. Library of Congress. Congressional Research Service. Hydrogen for Transportation and Storage of Energy. Archived Issue Brief No. 74089, by Migdon Segal. Washington, 1981. p. 1.

Hydrogen can, in principle, be derived from water using any primary source of high quality energy, and it can be combusted back to water in a closed chemical cycle releasing no pollution. Most R&D is now focused on the production of hydrogen by electrolysis or by the thermochemical breakdown of water using thermal energy from nuclear, coal, solar energy and other alternate energy sources. 164/

There are small-scale and large-scale strategies for using hydrogen as an energy storage material. Three possibilities exist for the dispersed storage of small quantities of hydrogen for transportation applications: compressed gas in cylinders, liquid hydrogen, and metallic hydrides. The storage of hydrogen gas in cylinders and its transport in pipelines has encountered serious problems resulting from embrittlement of the metallic containers. Liquid hydrogen is considered the most probable hydrogen-fuel for heavy duty surface transport and aircraft. However, the explosivity of hydrogen gas and the engineering difficulties associated with liquid hydrogen make the development of metallic hydrides attractive. 165/

When molecular hydrogen interacts with a metal or an alloy, it is dissociated to atoms which are absorbed in the metal. The resultant compound of metal and hydrogen is known as a metallic hydride. The density of hydrogen packing in most metallic hydrides exceeds that of liquid hydrogen. However, some metals, such as titanium and magnesium, have more desirable properties than others. 166/ Some of the desired features of a suitable hydride store

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164/ Carty, R. H., et al. Thermochemical Hydrogen Production, v. 1, Program Summary. Chicago, Gas Research Institute, June 1981. p. 1.

165/ Jensen, Energy Storage, p. 25-32.

166/ U.S. DOE. Basic Research Needs in Seven Energy-Related Technologies. (DOE/ER-0060) July 1980. p. 41.

are: (1) capacity for high density of hydrogen content, (2) low dissociation pressure at easily accessible temperatures, (3) constancy of dissociation pressure throughout decomposition, (4) good resistance to impurities, (5) lightweight, and (6) inexpensive. Metal hydrides may be the most feasible hydrogen storage scheme for a hydrogen car.

There are several possibilities for the bulk storage of large quantities of hydrogen produced from non-oil based primary energy sources: liquid hydrogen in insulated containers and compressed gaseous hydrogen in underground caverns. 167/ Hydrogen can be stored underground in a way similar to natural gas and proposed compressed air storage systems. The cost of storing hydrogen in depleted natural gas fields, aquifers, salt caverns, and excavated caverns has been estimated to be approximately equal to the cost for storing natural gas. 168/

Superconducting Magnetic Energy Storage

An electromagnet consists of a cylinder or torus wound with a coil of conducting wires that carry electric current. Energy can be stored in the magnetic field created by the circulating current. At temperatures near absolute zero, certain conductors—known as superconductors—lose all electrical resistance to direct current. A direct current at such temperatures will persist indefinitely and maintain the associated magnetic field for future energy withdrawal. A superconducting magnetic energy

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167/ Jensen, p. 25-32.

168/ Foh, Stephen, et al. Underground Hydrogen Storage. Chicago, Institute of Gas Technology, Dec. 1979. p. xii-xiii.

storage system (SMES) is essentially just a very large coil wound with superconducting material carrying a very large current and cooled to a very low temperature (see figure 15). 169/

In a practical application of these principles involving very large storage capacities, the coil structure would be placed underground in a tunnel with the rock supporting the coil forces. Energy is transferred into storage by applying a positive voltage to the coil to increase the current. Energy is transferred out of storage by permitting current to flow from the coil into the external AC circuit through an AC/DC converter. The overall efficiency of the SMES system is high (85 to 90 percent) because the energy is stored, transferred, and used as electrical energy and no conversion from one form to another is involved in the system as is the case for most other energy storage systems. 170/

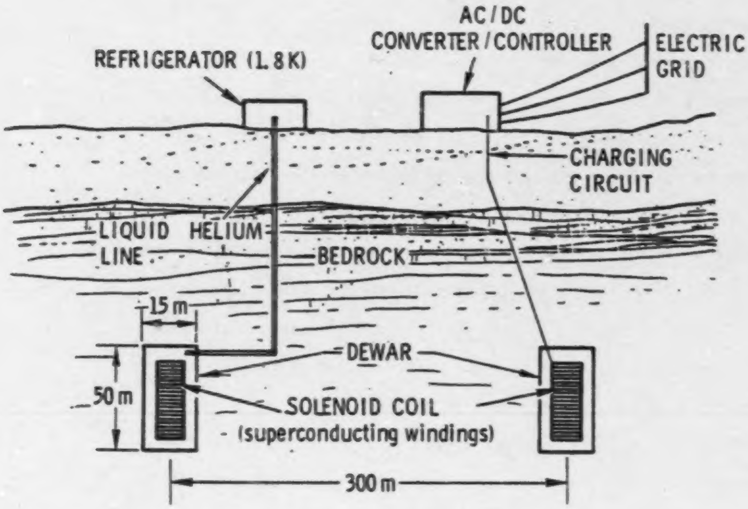
The DOE R&D program for SMES has sought to produce this technology for two types of storage uses: utility load-leveling and transmission line stabilization. The high efficiency of SMES is one of its main advantages for use in utility load-leveling. The magnet would be capable of storing 1,000 to 10,000 MWh of electricity and would have short response times. SMES can also be used by utilities to dampen system oscillations caused by short-term mismatches between customer demands and generating equipment. The addition of a small, 10 kWh magnetic energy unit to a system is expected to improve the transmission capability of a potential user by about 25 percent. 171/

169/ DOE, Energy Storage Systems, p. III-23. Also Aerospace Corporation, p. 2-260.

170/ Aerospace, p. 2-261 to 2-262.

171/ DOE, Energy Storage Systems, p. III-23 to III-24.

FIGURE 15: Superconducting Magnetic Energy Storage


AC/DC
CONVERTER/CONTROLLER
ELECTRIC
GRID
REFRIGERATOR (1.8K)
CHARGING
CIRCUIT
LIQUID HELIUM
LINE
BEDROCK
15 m
DEWAR
50 m
SOLENOID COIL
(superconducting windings)
300 m

STORAGE CAPACITY 1000-10,000 MWH

Source: The Aerospace Corporation. Characteristics and Applications of Energy Storage Systems. [ATR-77 (7538)-1]. Dec. 1977. p. 2-70.

The development of SMES is in its infancy and commercialization of this approach is considered to be further in the future than any of the other storage techniques. [172] Siting of SMES facilities by utilities should be less difficult than either pumped-hydro or compressed air unless it is found that the effects of the fringe magnetic fields from the large underground coil present health or ecological hazards. [173] However, SMES will likely be cost competitive with these systems only where very large storage capacities are required. [174]

There is no relevant construction or operating experience for the very large capacity SMES units needed in utility applications. [175] However, DOE and the Bonneville Power Administration have cooperated in the design and construction of a 10 kWh SMES device to provide transmission line stabilization. It will be used to allow 25 percent more (3,000 MW versus 2,410 MW) electric power generated by Washington hydro facilities to be transmitted to California to replace peaking power generated by burning oil. [176]

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[172] Aerospace Corporation, p. 2-264.

[173] Ibid., p. 2-266.

[174] Ibid., p. 2-276.

[175] Ibid.

[176] DOE, Energy Storage Systems, p. III-25.